Comparison of Alternative Manufacturing Systems for Global Supply Chain Business Strategies in Blood Sugar Monitoring Industry

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Abstract

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Comparison of Alternative Manufacturing Systems for Global Supply Chain Business Strategies in Blood Sugar Monitoring Industry

Director of Thesis: Gursel A. Suer

The direction of this thesis is to design systems to better understand the complexity of a business cycle. First questions are asked; what is the forecasted demand to satisfy customers? How will the company manufacture the products in an efficient way? This study emphasizes on the complexity of each step of the process. The study first introduces the demand allocation to satisfy current customers, but has a future strategy to expand upon their current market position. Reducing inefficiencies in the system, calculations were done for demand, standard deviation, demand coverage probability, and manufacturing cell utilization. Then a simulation model was designed to expedite the user enter values using VBA coding to simulate the manufacturing system. Final systems were compared to figure out if a future business strategy is manageable and desirable for the company.

Dedication

This dissertation is dedicated to my grandpa Willard Wilson, my parents Daniel and Cynthia, my brothers Brent and Nolan, along with the rest of my family.

Acknowledgements

Two people I would like to thank; my advisor Dr. Gursel A. Suer and my co-advisor Dr. Dusan Sormaz. Dr. Suer leader guided me as a mentor, a friend, and a person with endless knowledge. We had many detailed discussions about the topic but also about life. He led me through the valleys and peaks of the topic. Dr. Sormaz was an innovator with his ability to turn me into a functional programmer coming from a background with little experience. He was a true professor with his ability to teach me material out of his free time. I am grateful for both of these people for the joint effort of guidance and knowledge for this topic.

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1 Introduction

In this chapter and throughout this study, the general business model is based on the fact that pharmaceutical companies obtain huge cost to develop products. Once a pharmaceutical gains access to a product patent then it is a race to manufacturing and selling products until the patent runs out of life and other companies can manufacture knock offs of the same product. Section 1.1 describes Lifescan's current state business model. Section 1.2 describes the manufacturing system design. Section 1.3 describes mathematical modeling. Section 1.4 describes the simulation model which will determine if the manufacturing system design is achievable. Section 1.5 describes the supply chain design to deliver finished product from the manufacturing facility to the customers. Section 1.6 describes the research objective for this study. Section 1.7 describes the justification of this study.

1.1 Lifescan Background

This study is based on a pharmaceutical company called Lifescan and its blood sugar strip product. Although Lifescan has been producing blood sugar strips for many years, this study will use the assumption that Lifescan just launched the patent for this product. Pharmaceutical patents carry all different lengths of time, but for this study Lifescan's patent carries a 13-year period. Lifescan obtained its own patent for blood sugar strips but companies including Abbott, Bayer, and Roche also have a patent for blood sugar strips. Lifescan's desired rate of return is 80-90%. This required rate of return is based off of Lifescan having huge development cost to design the product (blood sugar strips) and tax rates on billions of dollars in revenue. These costs force pharmaceutical companies to be based in countries and or territories that have lower tax rates. Puerto Rico currently hosts many pharmaceutical companies, but these companies are looking for additional advantages in other regions in Europe and Asia. This study leads into the development of having two manufacturing facilities; Puerto Rico and China. Having two facilities will give Lifescan a competitive advantage to increase the revenue and/or overall market share of the company. Adding an additional facility in China will allow Lifescan to produce the product at a cheaper price allowing them to sell products in additional lower income countries.

1.2 Manufacturing System Design

Manufacturing System design is a study of how the blood sugar strips will be produced at the manufacturing facility. The total production of the manufacturing system is determined off of many factors including bottleneck machine, which is the constraint used in this study. Manufacturing systems can use three different approaches; 1) use an existing facility (one that the company uses already) 2) build additional space off of the existing facility in a situation when the current facility can't handle the current demand but a new facility is not affordable or desired 3) build a new facility. Existing facilities have limitations on the amount of capacity they can hold whereas building a new facility contains fewer limitations. In this study, two of the three types are used; building a new manufacturing facility in China and using a previous manufacturing facility (one that the company uses already) which is located in Puerto Rico. Lifescan manufacturing system design is based off Cellular Manufacturing which is an application of Group Technology. Manufacturing system design leads into the supply chain logistics dealing with how the raw materials reach the manufacturing facility and how finished products reach the customer hands, can become a very complex process.

1.2.1 Group Technology

Group Technology is an approach used across many fields of study, not just manufacturing. It is a study of grouping similar traits, objectives, trends, etc. together. In manufacturing, Group Technology is the study of manufacturing products that are similar based on machines, processes, or product similarities. Products with similar processes are clustered together to form groups. These groups are called product families, and they are processed in units called manufacturing cells.

1.2.2 Cellular Manufacturing

Cellular Manufacturing is the study of group technology in manufacturing to create manufacturing cells and product families. Individual products form families and these product families are grouped together based on manufacturing process similarities. Grouping products into families require that a set of machines are reserved to them. Manufacturing cells may contain one product family or multiple product families depending on factors such as cell utilization, demand coverage, number of machines, number of workers, etc. Manufacturing cells are combined together to form an optimal manufacturing system.

1.3 Mathematical Modeling

This study uses a mathematical model to minimize the total manufacturing system cost based on manufacturing cells, number of operators and number of machines in the manufacturing system as described in Chapter 4. These manufacturing cells can be based on product families being manufactured for 1 shift (8 hours), 2 shifts (16 hours), or 3 shifts (24 hours). This mathematical model identifies dedicated manufacturing cells, shared manufacturing cells, and remainder manufacturing cells. Dedicated manufacturing cells consist of only one product family in one manufacturing cell, shared manufacturing cells consist of two different product families in one manufacturing cell, and remainder manufacturing cells consist of more than two product families in one manufacturing cell. Optimization in the manufacturing system will reduce operating cost allowing product costs to be reduced and profit margins to increase.

1.4 Simulation

This study uses a simulation modeling package called Arena, to analyze the manufacturing system. The simulation will validate the results from the mathematical model to determine if the manufacturing system can meet the demand as expected. Some of the operating parameters will also be identified/fine-tuned through simulation analysis. Simulation results will be used to determine cost, revenue, and profit of the supply chain system. Time length for the simulation will be determined by the amount of shifts that the manufacturing facility will operate under. The simulation attributes will be called in from tables in Microsoft Excel using VBA so changes will not be made directly in Arena. This operation will allow slight changes to be made to the Arena model in a time saving and efficient way.

1.5 Supply Chain Design

This study uses a supply chain design featuring the advancement of going from one manufacturing facility that supplies all countries with a GPD per capita of at least

$10,000 to two manufacturing plants, each supporting a portion of the whole world market. Supply chain networks can be simple or extremely complex depending on what the customer wants. According to Chopro and Meindl (2007) study, there are two major types of supply chains; responsive and efficient. Responsive supply chain is used by 7-eleven where breakfast sandwiches are replenished in the morning, then once breakfast is over, lunch items are placed on the shelves, and then dinner items are placed on shelves after lunch is over. Seven-Eleven responds quickly to orders, which costs money but allows for a smaller area to support many more items**.** In efficient supply chains, it is important to find the optimal way to minimize the cost to deliver the product to the customer. Responsive supply chains are quicker to act to customers' wants and needs than an efficient supply chain because constant change is built into the system. Price-sensitive customers may wait longer for the product for a lower price whereas time-sensitive customers need the product right now even though product will cost more. Limited 2010 Business Strategy is described as a responsive supply chain to only neighboring countries with GDP per capita at least $10,000. Expanded 2011 Business Strategy will have two responsive supply chains to their GDP per capita related neighboring countries along with the China manufacturing facility being efficient in terms of cheaper labor rates. Manufacturing lower cost products due to cheaper labor in the China plant will allow Lifescan to enter into additional markets to increase the overall market share and revenue of the company.

1.6 Research Objective

Phase 1: is the manufacturing system design phase using demand. Demand for each manufacturing facility is determined based off of individual country's GDP per capita. Limited 2010 Business Strategy will allocate demand for countries with at least a GDP per capita of $10,000 to the Puerto Rico manufacturing facility. Expanded 2011 Business Strategy will allocate demand for high GDP per capita countries (GDP per capita > $20,000) for the entire world to the Puerto Rico manufacturing facility. Demand for the China manufacturing facility will support for low GDP per capita countries (GDP per capita < $10,000) for the entire world. Demand for middle tier countries or floating countries ($10,000 ≤ GDP per capita ≤ $20,000) demand can be supported by either the Puerto Rico manufacturing facility or the China manufacturing facility. Once the manufacturing system has been analyzed based off of demand functions then grouping of manufacturing cells is captured using mathematical modeling to find an optimal manufacturing system design. Simulation software called Arena is used to model the manufacturing system. Multiple iterations may be done for demand allocation of middle tier or floating countries to either manufacturing facility in Puerto Rico or China, but this study uses only one with 50% demand allocation going to both manufacturing facilities.

1.7 Justification

The objective of this research is to evaluate the performance of alternative supply chain strategies and compare them in a blood sugar strip industry. There are two types of studies being compared; 1) Ates' (2013) Lifescan study and 2) Lifescan study in this thesis document. This study goes into more detailed analysis of finite points from Ates' Lifescan study as shown below.

1.7.1 Ates' (2013) Lifescan Study

1) Demand:

   Forecasted demand values were based on three major regions of the market (North America, Europe, and China) which accounts for 80% of the market. These regions were not broken down based on countries, just one demand and price for each region so an overall price for North America. Statistical analyses were used to determine demand functions.

2) Manufacturing System Design:

   Grouping of manufacturing cells was based on a heuristic procedure. Grouping of manufacturing cells was based only on manufacturing cell utilization and demand coverage probability.

3) Simulation:

   Manufacturing system design was simulated in Arena. User values for the manufacturing system design were manually entered into the GUI aspect of Arena.

4) Supply Chain Analysis

   The supply chain analysis was based on two models: 1) Host Market Production Model (HMM) and 2) Globally Concentrated Production Model (GCM).

1. Host Market Production Model: Total of three manufacturing facilities (One in Puerto Rico, one in Europe, and one in China) with each manufacturing facility producing the demand for only its region. Revenues, Costs, and Profits were calculated based on raw material cost, procurement cost, inventory carrying cost, machine and operator cost, and transportation costs.
2. Globally Concentrated Production Model: One global facility in Puerto Rico which will manufacture all the demand for all three regions. Revenues, Costs, and Profits were calculated based on raw material cost, procurement cost, inventory carrying cost, machine and operator cost, and transportation costs.

5) Competition:

Discusses three basic strategies for competition; 1) Price Strategy 2) Quality/Reputation Competition and 3) Product Competition. However, he only focused on:

1. Price Strategy: if competitor cuts price then rapid response price strategy so Lifescan will cut price automatically. If competitors cut price then delayed response price strategy so Lifescan will wait one quarter to cut price.

1.7.2 Lifescan in this Study

1. Demand:

Six regions; North America, South America, Europe, Asia, Africa, and Oceania are studied because all these regions have demand from the blood sugar strip market. Forecasted demand and estimated price are computed for each country based off of world market revenue, 2011 GDP, 2011 GDP per capita, population, and diabetic population.

2. Manufacturing System:

   Uses a similar manufacturing system but manufacturing cells are grouped based on different shift types, manufacturing cell utilization, demand coverage probability to minimizing the total cost of the manufacturing system. A mathematical model (Sripathi 2005) was used and expanded upon to optimize the manufacturing system design.

3. Simulation:

   Arena model will use VBA coding to call user values into Arena model from excel. A user can run additional Arena model replications at a later time period. The user will be able to obtain results from the simulation without completely knowing how to operate Arena or the model devoloped in this study.

The main differences between Ates' study (2013) and this study are that this study can satisfy more customers because of the 2011 Expanded Business Strategy. Demand and price equations are different; this study goes into a much detailed analysis because each country has a forecasted demand and estimated price per vial. Furthermore, this study will optimize the manufacturing system by using mathematical models for grouping manufacturing cells together. In this study, simulation software will read the information from a Microsoft Excel sheet to Arena using VBA coding so the simulation can be run many different variations easily. Ates' study (2013) simulated competition between the companies but this study will not include this type of analysis.

2 Literature Review

Business Strategy at cooperate level consists of all areas and all aspects of the company. Detailed analysis consists of the business strategy including inside and outside the manufacturing facility. Strategies relating on how the products are delivered to the customers are considered supply chain modeling, section 2.2. Strategies relating to how the facility runs the day-to-day operations and how the products will be manufactured are considered in the manufacturing system design, section 2.3. Both coincide with each other to create the complete business strategy along with the market structure.

2.1 Business Strategy

According to Caves (1980), “Market structure refers to certain stable attributes of the market that influence the firm’s conduct in the marketplace”. Factors that affect the market structure are the amount of buyers and sellers, cost to enter or exit the market, and product variation or product competition. The company’s business strategy is determined by top managers along with the company’s strengths and weakness.

Caves (1980) investigated the effects of both corporate strategy and organizational structure. The study of organizational behaviors and administration lie at the intersection with industrial organization as a branch of economics. Corporate strategy came about as a business decision-making process as a long term plan to achieve company goals. Workers knowledge and skill, experience in the market, company assets such as machines or buildings are factors used to determine the decision making process. The other key concept is that of organizational structure, the arrangements whereby the firm motivates, coordinates, appraises, and rewards the inputs and resources that belong to its coalition.

Market structure can create a competitive market which allows a company to affect their market value and value of competitors. In a competitive market, a company needs a competitive strategy to compete and stay alive. A brewing company in the U.K. was studied by (Johnson & Thomas 1987). Their focus was on product strategies. According to Johnson & Thomas (1987) unrelated product strategies provided greater returns at less risk than companies consistently following single, dominant or related product strategies. Strategic management is described as designing a real life system in the environment that the system will operate in. This paper focuses on the characteristics of the industry environment, the strategies followed by companies within the industry, and the performance achieved by companies adopting different competitive strategies all relating to the U.K. brewing industry. `

Competitive strategies can create risk, but increasing market shares of a company can lead to high levels of profit; whereas if these strategies decrease the market shares then profit levels may vanish. According to Roberts (1999), scholars are trying to understand the factors that allow some (but not all) companies to sustain relatively high profit levels over time. Competition is experienced in all different types of ways from company to company. This article embraces product innovation, product-market competition and the prospect that numerous product innovations may be embodied within a single company dealing with a pharmaceutical company. Companies vary in their ability to control and compete with competition by driving companies out or allowing companies to enter the market. Roberts (1999) discusses that when Sony produces a new product, its profit and sales increase rapidly; once other firms reverse engineer the product then sales come down to normal. This shows that Sony does have the ability to sustain a competitive advantage. This is the same breakdown that pharmaceutical companies experience when a new product is released.

Companies experience globalization when they enter into new regions and new markets across the globe. Buckley and Ghauri (2004) study was based on analyzing globalization, with a focus on economic geography, arising from the changing strategy and the external impact of multinational enterprises (MNEs) on the world economy. Factors included in the study were government policies, location and ownership, such as finding the optimal location for the MNEs, strategies of MNEs, control strategies. Globalization can be affordable for customers and companies due to expansion of networks from advancements of communication and the development of cheap transportation. Globalization can destroy uniqueness in products causing standard products to be produced.

Parker (2009) study was analyzing current blood sugar strip market revenue based on individual countries. These countries were broken down into six regions or continents which are Africa & Middle East, China, Europe, Latin America, North America & the Caribbean, and Oceana. Each region's blood sugar strip demand was organized based on the world's 2011 countries existence.

2.2 Supply Chain Modeling

Supply chain networks can create competitive advantages allowing companies to increase efficiency which results in a positive asset for the company. According to Min & Zhou (2002) there are two structural dimensions of a supply chain network; horizontal and vertical. Horizontal refers to the number of tiers while the vertical refers to number of suppliers and customers represented within each tier. Linkage between supply chain activates can lead to a competitive advantage. Four strategy links are described; 1) managed process links 2) monitored process links 3) not-managed process links 4) non-member process links. The article discusses IT-driven models for the improving supply chain efficiency. IT models consist of four major types: 1) deterministic (non-probabilistic); 2) stochastic (probabilistic); 3) hybrid; 4) IT-driven. Based off of the visibility throughout the supply chain IT-driver models have developed software application 1) WMS; 2) transportation management systems (TMS); 3) collaborative planning and forecasting replenishment (CPFR); 4) material requirement planning (MRP); 5) distribution resource planning (DRP); 6) ERP; 7) geographic information systems (GIS).

Supply chain efficiency deals with many factors over many companies, especially Fortune 500 companies. Schmenner, Huber and Cook (1982) interviewed powerful multination Fortune 500 companies about selecting a plant location. Results showed that location can be broken down into factors such as distance, environment, worker, government policies, taxes, etc. to guide a company in finding the optimal solution.

Ozer & Raz (2011) studied a supply chain model involving two companies; one is a major manufacturer and the other is a small manufacturer. A game theory approach was used to find the optimal profit for the manufacturers using six different scenarios. Scenarios use information about whether processing costs are known by the company, or the information is public information, or the information is not known.

Chopra & Meindl (2007) studied competitive and supply chain strategies. "A company's competitive strategy defines, relative to its competitors, the set of customer needs that it seeks to satisfy through its products and services". Wal-Mart is described to have a competitive advantage from selling products at lower prices whereas McMaster-Carr (Online distributor of many products) is described to have a competitive advantage from having a convenience, availability, and responsiveness supply chain network. A cell phone company developing a new product may face high levels of uncertainty for both demand and supply causing the supply chain structure to be highly uncertain. On the other side, a coffee manufacturer faces a low level of demand uncertainty but a high level of supply uncertainty based on weather. This type of situation would create an intermediate level of supply chain uncertainty. Supply chain responsiveness is explained to have the ability to respond to wide range of quantities demanded, meet short lead times, handle a large variety of products, build highly innovative products, meet a high service level, and handle supply uncertainty. The responsiveness spectrum is described as four different categories including highly efficient, somewhat efficient, somewhat responsive, and highly responsive.

Klibi, Martel & Guitouni (2010) discussed supply chain design under uncertainty with risk factors associated with it. Risk factors can be associated with all areas of the manufacturing system. Piedro, Mula & Poler (2009) study focused on supply chain network and the uncertainty that it brings with it. A total of twenty one approaches is analyzed; Eleven approaches cope with the uncertainty and ten approaches seek to reduce the uncertainty. Supply chain networks with uncertainty can deal with the uncertainty by allocating a cost. This cost is set aside for when uncertainty happens. If a supply chain has high uncertainty then a higher cost will be allocated to the supply chain network.

2.3 Cellular Manufacturing Systems Design

According to Suer, Huang, & Maddisetty (2010) there are four types of manufacturing systems; 1) product layout; 2) process layout; 3) fixed layout; 4) cellular layout. The article studies a jewelry company which has 30 products and 18 machines in the system. Deterministic mathematical model, stochastic non-linear mathematical model, discreet event simulation, and genetic algorithm are used to compare results about cell formation and manufacturing system design.

Offodile, Mehrez & Grznar (1994) described group technology along with three machine part grouping techniques; 1) visual inspection-based method; 2) part characteristic-based system; 3) production process-based system. A five level scheme is used to breakdown the information.

Egilmez & Suer (2012) described cellular manufacturing systems (CMS) which consist of cells, machines, equipment, workers, etc. CMS can lead a manufacture system to benefit from lower leadtime and less work-in-process inventory. The research is geared towards stochastic CMS design, stochastic CMS control, and the integration of CMS design and CMS control. As shown before, this article is based off of the jewelry manufacturing company.

Ates' (2013) discussed two types of manufacturing designs for the same blood sugar strip manufacturing company that is studied in this work; one being a fast manufacturing system and two being a slow manufacturing system. The difference between the two types of systems is number of machines, number of workers, and the processing times for each operation which leads to different bottleneck times, between the fast and slow manufacturing systems. Ates' describes the nine different operations to produce a blood sugar strip, which consists of two phases. Phase one is the fabrication phase which consists of operations 1, 2, & 3. These three operations manufacture the subassembly for each product family. Phase two is the packaging phase which consists of operations 4-9. These five operations are where the 36 different product types are packaged. Phase one and phase two are designed off of a connected strategy manufacturing system. There are five families which consist of 36 different products.

Ates' (2013) used mean capacity requirements, demand coverage probability, and expected cell utilization calculations. Mean demand for vials are used to find the mean capacity requirements and the standard deviation of the system. This allows probabilities to be placed based off of a normal distribution curve that determines demand coverage probability. The NORMSDIST function in excel was used to determine the probability of the manufacturing system satisfying the demand. Expected cell utilization was used to find workload in the cells to satisfy all demand. A cell is organized by families but once all demand has 100% probability of being satisfied then grouping of cells with different families can be used to figure out optimal cell utilization for each cell and to minimize the number of cells or number of workers or number of machines.

According to Bhatnagar and Sohal (2005) there are three types of supply chain uncertainty; 1) supply uncertainty 2) process uncertainty 3) demand uncertainty. Supply uncertainty is directly related to the supplier performance variability in terms of products being delivered not on-time (either arrives early to the facility or arrives late) or products having defects. Process uncertainty is related to unreliability of the production process due to breakdowns of machines. Demand uncertainty is related to volatile demand fluctuations and inaccurate forecasting. Major factors that affect the competitiveness of the plant location supply chain network are categorized into one of these areas; cost, infrastructure, business services, labor, government, customer/market, proximity to suppliers.

According to Bukh and Nielsen (2008), three interrelated elements form the basis of a business model; 1) characteristic of the way the company thinks, how the company operates', and capacity for value generation. The business model is composed of these three components; 1) generic strategy referring to customers, competitors, etc. 2) Broad model referring to activities and organization, human, physical and resources, and 3) Narrow model referring to production factor and inputs. Narrow business model goal is referred to as spelling out the makeup of the company in terms of what customers will the company target, risks within the company, what makes your business different from others, etc. Broad business model refers to the culture of the company in terms relationships with other companies and also inside the company.

Maddisetty (2005) used mathematical modeling software called OPL to model a manufacturing system design. The objective was to minimize the number of manufacturing cells using demand coverage probabilities and manufacturing cell utilizations. Manufacturing cells were grouped based on constants such as maximum cell utilization and minimum demand probability coverage. Cells can be grouped into three different types of formations; dedicated cells, shared cells, and remainder cells. The model optimized the number of manufacturing cells based off of manufacturing cell utilization and manufacturing cell demand probability coverage. The model is shown below.

Indices for the model:

i	Index for family ($i = 1, 2 \ldots p$)
j	Index for coverage segment ($j = 1, 2 \ldots q$)
k	Index for cell ($k = 1, 2 \ldots r$)

Parameters for the model:

p	Number of families
q	Number of coverage segments
r	Number of cells
b_{ij}	Expected utilization for part family ‘i’ and coverage segment ‘j’
c_{ij}	Probability of covering demand for part family ‘i’ and coverage segment ‘j’
m	Maximum allowable expected utilization for a cell

n Minimum demand coverage probability for each family

Decision variables for the model:

$$X_{ijk} = \begin{cases} 1 & \text{if family 'i' is assigned to coverage segment 'j' and cell 'k'} \\ 0 & \text{otherwise} \end{cases}$$

$$Y_k = \begin{cases} 1 & \text{if cell 'k' is formed} \\ 0 & \text{otherwise} \end{cases}$$

Mathematical Model:

$$\text{Minimize} \quad Z = \sum_{k=1}^{r} Y_k \qquad \textbf{(Equation 2.1)}$$

Subject to

$$\sum_{j=1}^{q} X_{ijk} \le Y_k \qquad \begin{cases} i = 1, 2 \ldots p \\ k = 1, 2 \ldots r \end{cases} \qquad \textbf{(Equation 2.2)}$$

$$\sum_{j=1}^{q} \sum_{i=1}^{p} b_{ij} * X_{\text{ijk}} \le Y_k * \text{m} \qquad k = 1, 2 \ldots r \qquad \textbf{(Equation 2.3)}$$

$$\sum_{j=1}^{q} c_{ij} \left[\sum_{k=1}^{r} X_{\text{ijk}} \right] \ge \text{n} \qquad i = 1, 2 \ldots p \qquad \textbf{(Equation 2.4)}$$

$$\sum_{k=1}^{r} X_{ijk} \le 1 \qquad \begin{cases} i = 1, 2 \ldots p \\ j = 1, 2 \ldots q \end{cases} \qquad \textbf{(Equation 2.5)}$$

$$\sum_{k=1}^{r} X_{i,(j-1),k} \ge \sum_{k=1}^{r} X_{ijk} \qquad \begin{cases} i = 1, 2 \ldots p \\ j = 2, 3 \ldots q \end{cases} \qquad \textbf{(Equation 2.6)}$$

The objective function in the model is to minimize the number of manufacturing cells which is shown in Equation 2.1. Equation 2.2 is a constant to ensure that only one coverage segment from each family is assigned to a manufacturing cell. Equation 2.3 constant ensures that manufacturing cell utilization does not exceed the maximum allowed manufacturing cell utilization. Equation 2.4 constant ensures the minimum bound for demand coverage probability for each family. Equation 2.5 constant ensures that only one manufacturing cell can contain only one coverage segment for each family. Equation 2.6 constant ensures that coverage segments are assigned in order so that coverage segment two can be assigned only after coverage segment one had been assigned.

Maddisetty (2005) also used a heuristic algorithm to select manufacturing cell groupings. The algorithm was designed to reduce the number of manufacturing cells in a manufacturing system. The algorithm is based on expected manufacturing cell utilizations and demand coverage probabilities to form manufacturing cells based on certain requirements such as minimum demand coverage of a family and highest manufacturing cell utilization that one manufacturing cell can run on.

2.4 Simulation Studies

Aizi, Bukchin, and Masin (2001) developed a mathematical model and a genetic algorithm to optimize a manufacturing system. Formulation was done to increase efficiency and capacity requirements based on grouping manufacturing cells. Cells were grouped based on part and machine similarities. Eight different tests ranging from 13 parts to 25 parts were analyzed to determine the optimal manufacturing system.

Renna & Ambrico (2011) study compares cellular manufacturing system to two other systems; remainder cells and fractal cells. Arena simulation software package is used to compare these different types of systems. These systems are analyzed under these performance measures; machine breakdown, production time variability, production mix changes, and demand fluctuations. These systems are compared based on throughput, throughput times of the parts, work in process, manufacturing utilization, and due date performance (tardiness). The simulation was conducted to describe the difference between a manufacturing system with all manufacturing cells having the same machines and a manufacturing system with manufacturing cells having different types of machines that are used for different products.

Lobo (2006) study was used for medical devices by comparing two manufacturing system designs; connected manufacturing cells and disconnect manufacturing cells. Connected manufacturing cell is explained as once a product enters a manufacturing cell then that will product will complete all of its operations and exit the manufacturing cell. Disconnected manufacturing cell is explained as a product can perform some operations in one manufacturing cell and other operations in another manufacturing cell. This will complexity to the manufacturing system bout can create great value. An Arena simulation model was developed to analyze both manufacturing system designs.

Pirard, Iassinovski, and Raine (2011) study consisted of a simulation model for various supply chain network design evaluations. The model simulates customer demands to distribution centers and production sites along with replenishment orders. These factors are calculated to find a global optimal solution for the supply chain system. Four different types of decision aid problems are considered for this study; 1) location problem 2) capacity problem 3) control problem 4) allocation problem. These four logistical problems are solved with the intent of maximizing profit.

3 Overall Framework of the Study

This chapter describes forecasted demand and estimated pricing equations, manufacturing system design, and supply chain design as shown in Figure 3.1. Demand is a forecasted amount of units that a country will purchase at a particular price. Price is the currency amount that the company will charge the customer to make a desired profit. Individual countries' prices are based on buying power and are scaled to be in 2011 dollar amounts. Manufacturing system design is identifying resources (machines, number of manufacturing cells, number of operators, etc.) that are needed to meet customer demands. Supply chain design is the network process plan based on four phases;

1) How raw materials reach the facility
2) How/if suppliers are needed/identify
3) How products are manufactured at the facility
4) Transportation cost of products from the manufacturing site to the customer hands

In this study, two business strategies will be considered; Limited 2010 Business Strategy and Expanded 2011 Business Strategy described below:

1) Limited 2010 Business Strategy supply chain design uses an existing manufacturing facility in Puerto Rico. This business strategy will satisfy demand for countries with GDP per capita of at least $10,000. Supply chain design will operate under a responsive system to neighboring countries of at least $10,000 GDP per capita to Puerto Rico.

2) Expanded 2011 Business Strategy supply chain design uses an existing manufacturing facility in Puerto Rico and a new manufacturing facility in China. Puerto Rico's manufacturing facility forecasted demand for this approach will be only high GDP per capita countries ($20,000 < GDP per capita). China manufacturing facility forecasted demand for this strategy will be only low GDP per capita countries ($10,000 > GDP per capita). Forecasted demand for countries with a GDP per capita ($10,000 ≤ GDP per capita ≤ $20,000) can be allocated to either the Puerto Rico manufacturing facility or the China manufacturing facility. China manufacturing facility supply chain design will operate under an efficient system because of cheaper product cost due to cheaper labor prices. With this strategy, Lifescan will generate additional global revenue and additional global market shares because the China manufacturing facility will produce a lower costing product which will allow Lifescan to attract additional customers. This study follows the general methodology shown in Figure 3.1:
3) Demand and Pricing (described in Section 3.1): is a forecasted function dependent on multiple individual country categories resulting in a revenue amount that is achievable.
4) Manufacturing System Design (described in Section 3.2): is allocating the demand (per country) to the desired manufacturing facilities. Manufacturing facilities need to be able to support a percentage or all the desired capacity required to satisfy demand.

5) Supply Chain Design (described in Section 3.3): is the network process plan resulting in the transportation of finished goods from the manufacturing plant to the customer.

6) Compare and Determine the Best Business Strategy (Described in the conclusion of the study): Compares the two business strategies based on calculations of Lifescan global revenue and Lifescan global market share to determine what the worth is to Lifescan to add an additional manufacturing facility.

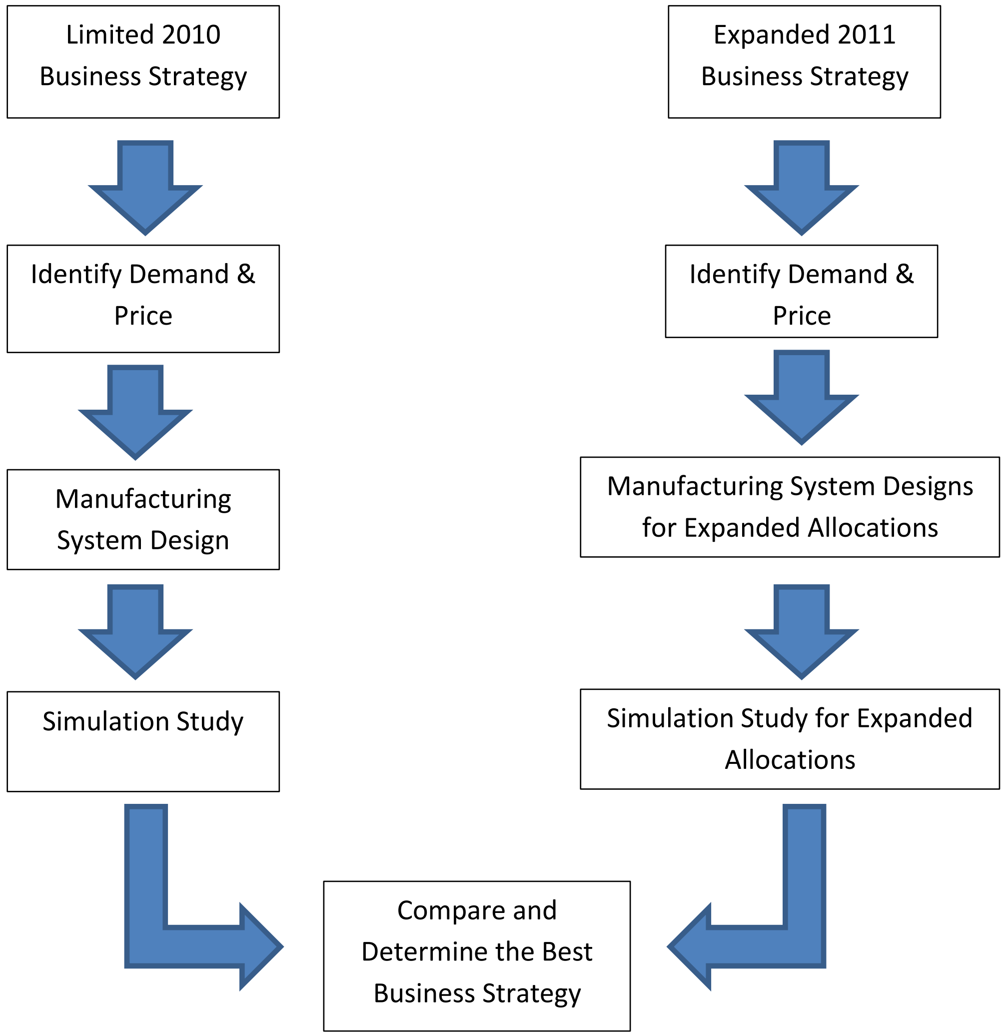

Figure 3.1 General Methodology Used

General Methodology describes each of the two business strategies. Each strategy uses similar steps as described below;

3.1 Demand and Pricing

Demand in a market, on a product, is dependent on sales price, customer income, location, exposure to the product, consumer lifestyle, product quality, etc. Demand is forecasted based on monetary factors. These factors include GDP per country, GDP per capita, percentage of diabetes, and vials purchased in one year. These factors and their relationships are described in equation 3.1. In this case, country revenue information is available. However, demand will be forecasted and price will be estimated to perform this study.

3.1.1 Demand Forecast

Equation 3.1 is used to forecast demand for each country. Constants are used to calculate the amount of vials that an individual will purchase for a calendar year, which are described below in bullet 4.

$$\textbf{Total Market Demand (Country } i\textbf{)} = \left(\frac{X_i * Z_i * A_i}{Y_i}\right) \qquad \textbf{(Equation 3.1)}$$

1) X_i = 2011 GDP per country i
2) Y_i = 2011 GDP per capita per country i
3) Z_i = Diabetes percentage per country i
4) A_i = Vials purchased by one person in country i
    - $A_i = 4\left(\frac{Vials}{Year}\right) = \left(\frac{52*2}{25}\right)\left(\frac{Vials}{Year}\right)$
        i. A_i: Customer purchases 2 strips per week for 52 weeks in a year. Each vial contains 25 blood sugar strips.

Table 3.1 describes Equation 3.1 with United States as the country. This demand is satisfied by all competitors including Lifescan. Lifescan will manufacture only their market share percentage of the total demand for the United States, which is discussed in Table 3.3 in section 3.3.

Table 3.1 Total Global Market Demand

Country	2011 GDP	2011 GDP per Capita	Population Percentage Diabetic	2011 Vials Purchased by one customer	2011 Demand
The United States	14,991,300,000,000	$48,113.00	10.20%	4	127,126,773

3.1.2 Price Estimation

Consequently, the demand forecasted in Equation 3.1 will be used to calculate the price per vial using Equation 3.2. Along with forecasted demand and countries yearly revenue, buying power was factored into Equation 3.2. Buying power allows individual vial pricing to be distributed based on GDP per capita. This distribution allows for a pricing structure to be set across the whole market to produce overall market revenue by charging higher GDP per capita countries a higher product price than lower GDP per capita countries. Upper bound price was set at $30.00/vial and lower bound price was set at $7.20/vial.

Market Price (Country i) = $\$\mathbf{7.20} \leq \frac{\boldsymbol{R_i}}{\boldsymbol{Q_i}} \leq \$\mathbf{30.00}$ **(Equation 3.2)**

1) Q_i = Total Market Demand of country i
2) R_i = Total Market Revenue in terms of year 2011 for country i

Table 3.2 describes Equation 3.2 with United States as the country. Lifescan will sell an individual vial to customers at this price in The United States.

Table 3.2 Price

Country	2010 Revenue	2010 Demand	2010 Price/Vial
The United States	$ 2,732,080,000	127,126,733	$ 21.49

3.2 Manufacturing System Design

According to Ates' (2013), Puerto Rico manufacturing facility operates using a fast manufacturing system for the blood sugar strip production line. This manufacturing facility operates on a connected structure between two areas; Fabrication and Packaging. Once fabrication of a product begins processing in a manufacturing cell then that same manufacturing cell will perform the operations needed for packaging. Lifescan sells a total of five different products so the manufacturing system design contains five product families. These product families are divided into manufacturing cells to optimize utilization and demand coverage which is described in Chapter 4. An optimization program called OPL is used to group product families together to form manufacturing cells. Assigning product families is optimized based on utilization, demand coverage, number of operators, and number of machines which is also described in Chapter 4. Manufacturing system design also uses a discrete event simulation called Arena to analyze manufacturing cells with product data. The simulation is used to verify that the manufacturing system design is capable of producing the required demand.

3.3 Supply Chain Design

Supply Chain design is based on two different business strategies;

1) 2010 Limited Business Strategy manufactures demand for countries with a GDP per capita of at least $10,000 from existing manufacturing facility, which is located in Puerto Rico, described in section 3.3.1 and Figure 3.2.

2) Expanded 2011 Business Strategy manufactures demand for all countries with a portion of the demand being manufactured in the existing manufacturing

facility, which is located in Puerto Rico, and the other portion of the global demand being allocated to another manufacturing facility, which is located in China, described in section 3.3.2 and Figure 3.3.

The Puerto Rico manufacturing facility was built and met demand before 2011 whereas the China manufacturing facility is under a detailed analysis, in this study, to determine if building an additional facility will increase Lifescan global market share and global market revenue.

3.3.1 Limited 2010 Business Strategy

Limited 2010 Business Strategy is described as allocating demand for countries, with a GDP per capita of at least $10,000, to an existing manufacturing facility in Puerto Rico. These countries are referred to as satisfied customers. Countries with a GDP per capita under the $10,000 threshold, demand will not be satisfied. These customers are referred to unsatisfied customers. Demand for unsatisfied customers will not be manufactured by Lifescan or any competitor. The blood sugar strip market for unsatisfied customers does not exist due to product price. Lifescan and its competitors simple cannot produce products cheap enough to sell products to unsatisfied customers and still gain the desired 80%-90% margins. This strategy will focus only on satisfied customers.

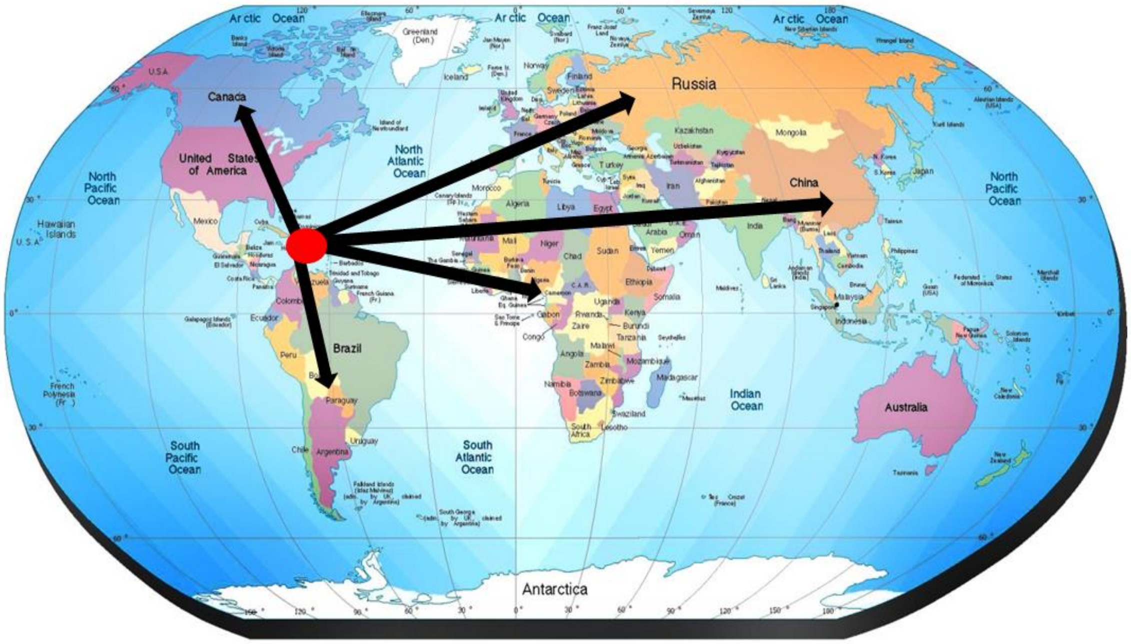

Figure 3.2 Limited 2010 Business Strategy Approach World Market

3.3.1.1 Satisfied Customer Market Analysis

Limited 2010 Business Strategy global market revenue is based on Lifescan and all its competitors' total sales. Lifescans' global revenue is based on the market share that Lifescan has captured in all regions. Lifescan has a presence in all six regions, thus they capture a percentage in all regional markets. Table 3.3 describes the percentage that Lifescan holds in each of the six regions. Market shares for Asia, Europe, and North America were obtained from Ates' (2013) study, with Lifescan having a starting 2010 global market share percentage of 26.37%. Additional calculations were done to compute percentage of market shares for Africa and Middle East, Latin America, and Oceana. These calculations are done using Equation 3.3.

Table 3.3Regional Market Share for Lifescan

Regional Market Shares of LifeScan		
Year	Region	% of Region
2010	Asia	25.41%
2010	Europe	23.89%
2010	N.America	31.04%
2010	Africa & Middle East	25.56%
2010	L. America	25.56%
2010	Oceana	25.56%

Table 3.4 describes the percentage of the global market share for each of the six regions. These 2010 market shares are based on total revenue for those regions divided by the total world revenue.

Table 3.4 Global Market Share Percentage

Global Market Share						
Year	Africa & Middle East	Asia	Europe	L. America	N.America	Oceana
2010	9.23%	31.27%	26.49%	8.21%	23.42%	1.39%

Since Lifescan's global market percentage is known, these three regions' percentage of market share can be estimated. Tables 3.3 and 3.4 are combined to calculate Lifescan's missing three regions.

$$\boldsymbol{Lifescan\ Global\ Market\ Share} = \mathbf{26.37\%} = \sum(\boldsymbol{R_i} * \boldsymbol{G_i}) \qquad \textbf{(Equation 3.3)}$$

- Lifescan percentage of region i market share in regional market = R_i
- Lifescan percentage of region i market share in global market = G_i

$$26.37\% = (25.41\% * 31.27\%) + (23.89\% * 26.49\%) + (31.04\% * 23.42\%)$$
$$+ (9.23\% * x) + (8.21\% * x) + (1.39\% * x)$$

- Solving for x will give a value of 25.56%. So these three regions will obtain this regional market share percentage.

3.3.1.2 Lifescan Satisfied Customer Market Analysis

According to Table 3.5, the number of satisfied customers is 75. These customers are present in all six regions, with Europe containing the most at 34.

Table 3.5 Number of Satisfied Customers per Region

Number of Satisfied Customers per Region							
Customer Type	Africa & the Middle East	Asia	Europe	Latin America	Noth America & The Caribbean's	Oceana	Total
Satisfied	12	9	34	5	11	4	75

According to Table 3.6, Lifescan satisfied customers allocate sales of123,990,578 vial/year. Highest demand region is North America and the Caribbean's with 43,828,490 vials/year. Each region vial demand is further broken down into the number of satisfied customers in that particular region. Europe will have 34 vial demands for 34 different satisfied customers totaling 36,645,487 vials. These values are calculated based on the global market demand multiple by Lifescan regional market share.

Table 3.6 Regional Vial Demand

Region Vial Demand							
Customer Type	Africa & the Middle East	Asia	Europe	Latin America	Noth America & The Caribbean's	Oceana	Total
Total	13,260,537	17,967,268	36,645,487	10,215,015	43,828,490	2,073,782	123,990,578

According to Table 3.6, satisfied customers purchase vials at a maximum price of $30.00 in four regions. Satisfied customer purchase vials at a minimum price of $7.20 in five different regions. Highest average price is the region of Latin America. Prices for each region are further broken down into the number of satisfied customers in that particular region. Asia will have 9 prices for 9 different satisfied customers with an average price of $17.63.

Table 3.7 Regional Price (Max, Min, and Average)

Customer Type	Africa & the Middle East			Asia			Europe			Latin America			North America & the Caribbean's			Oceana		
	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average
Satisfied	$30.00	$ 7.20	$13.00	$30.00	$ 7.20	$17.63	$30.00	$ 7.20	$19.29	$28.62	$ 7.83	$20.58	$30.00	$ 7.20	$13.03	$23.75	$ 7.20	$14.44

The global market analysis for Limited 2010 Business Strategy is based on countries' buying power. Buying power is the ability to purchase a product within means of the customers' income. Customers that have a higher income will have the ability to allocate more of their income to purchase products. Lifescans' satisfied customers will be able to purchase all demand, which is manufactured from the Puerto Rico manufacturing facility. This facility will meet demand for 75 different countries across the globe according to Table 3.5. Demands for satisfied customers are sold at different price amounts. Table 3.8 describes the total global market revenue, Lifescan revenue, and Lifescan market share for the year 2010.

Table 3.8 2010 Global and Regional Markets

Region	Global Market Revenue	Lifescan Revenue of World Market	Lifescan Market Share based on World Market
Africa & the Middle East	420,260,000	107,418,456	1.21%
Asia	1,436,050,000	364,900,305	4.11%
Europe	3,237,860,000	773,524,754	8.71%
Latin America	605,250,000	154,701,900	1.74%
North America & The Caribb	3,008,190,000	933,742,176	10.51%
Oceana	176,400,000	45,087,840	0.51%
Total	8,884,010,000	2,379,375,431	26.78%

Limited 2010 global market revenue for satisfied customers totals just over $8.88 billion. Of this global revenue amount, Lifescan has 2010 yearly sales of just under $2.38 billion. Lifescan's market share is based on world market which is calculated by dividing Lifescan revenue of world market by the total global market revenue as shown in Equation 3.3. As shown before, Lifescan's actual market revenue at the beginning of

2010 is 26.37% and by allocating additional sales for the increase in world population will generate an ending 2010 Lifescan global market share percentage of 26.78%.

$$\boldsymbol{Lifescan\ Market\ Share\ based\ on\ World\ Market\ Region\ i} = \frac{\boldsymbol{LR_i}}{\sum_{i=1}^{6} \boldsymbol{R_i}}$$

(Equation 3.4)

3.3.1.3 Expanded 2011 Business Strategy

Expanded 2011 Business Strategy is described as allocating demand for all countries, to an existing manufacturing facility in Puerto Rico or a new manufacturing facility located in China. This strategy expands off of the concept from 2010 Limited Business Strategy of supplying demand for countries with any GDP per capita. Countries with a GDP per capita less than $10,000 are referred to low income customers. Countries with a GDP per capita from the range of $10,000 to $20,000 are referred to floating income customers. Countries with a GDP per capita greater than $20,000 are referred to high income customers. 2011 Business Strategy focuses on a potential increase in Lifescans' global market revenue and market share percentage. An assumption was made that Lifescan will be the first company to build an additional facility for capturing these low income customer markets. Lifescan will only be able to capture a percentage of these markets, because competitors will soon follow and obtain the remaining market shares.

3.3.2 Expanded 2011 Business Strategy Manufacturing System Allocation

Lifescans' manufacturing system is expanding from one manufacturing facility to two manufacturing facilities. These facilities will manufacture demand for different types of customers. Due to lower wage rates in China, Lifescan can lower its product costs while still obtaining the desired rate of return of its sales. This concept allows Lifescan to enter into these untapped markets. Hence, Chinas' manufacturing facility will satisfy demand for all low income customers. Puerto Rico manufacturing facility will satisfy demand for all high income customers. The remaining demand for floating customers can be satisfied by either manufacturing facility. This concept of different manufacturing facilities supporting different markets is shown in Figure 3.3.

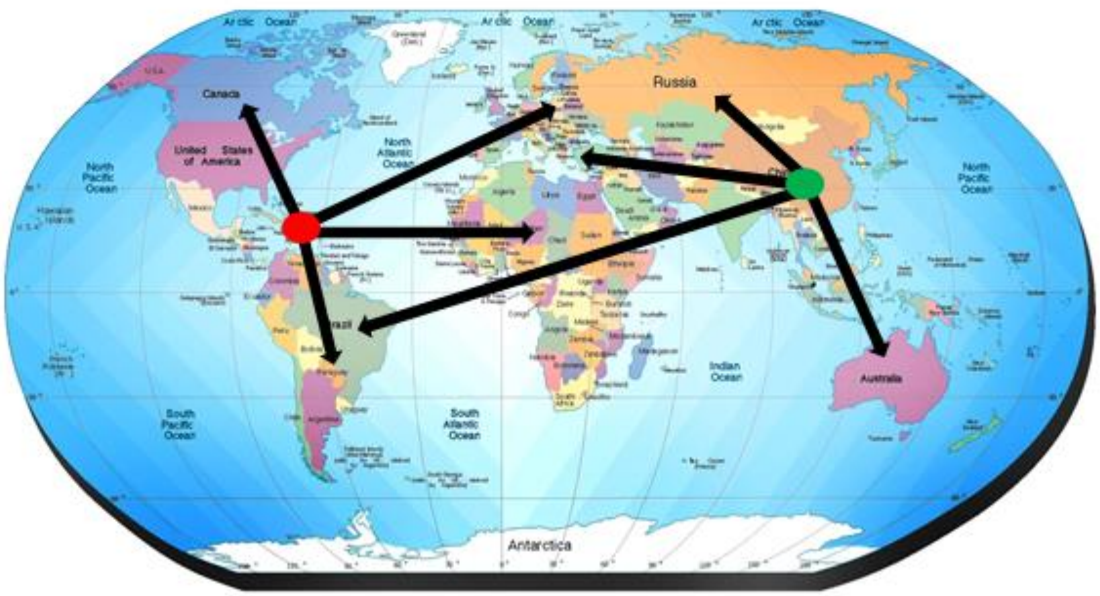

Figure 3.3 Expanded 2011 Business Strategy World Market

3.3.2.1 Expanded 2011 Business Strategy World Market Analysis

Expanded 2011 Business Strategy global market analysis is based on the concept that the global market is growing due to Lifescan and its competitors obtaining new customers in low income areas (GDP per capita < $10,000). Since Lifescan is the first company to enter into these markets, they can obtain a higher market share percentage. This percentage was assumed to be 35%. During 2011 and into the future other competitors will compete for the remaining 65% market share percentage for these low income areas. Lifescan is only increasing its market share value in these markets so market share percentages, revenue and vial demand will remain consistent for floating and high income customers from 2010 to 2011. Tables 3.9 describes Lifescan regional market share based on customer type.

Table 3.9 Regional Market Share for Lifescan

Regional Market Shares LifeScan				
Year	Region	High Income Customers	Floating Income Customers	Low Income Customers
2011	Asia	25.41%	25.41%	35.00%
2011	Europe	23.89%	23.89%	35.00%
2011	N.America	31.04%	31.04%	35.00%
2011	Africa & Middle East	25.56%	25.56%	35.00%
2011	L. America	25.56%	25.56%	35.00%
2011	Oceana	25.56%	25.56%	35.00%

Table 3.10 describes the expansion of the global market based on the amount of customers that Lifescan or any competitor will satisfy. Individual countries are now referred to as customers.

Table 3.10 Number of Customers

Number of Customers							
Customer Type	Africa & the Middle East	Asia	Europe	Latin America	Noth America & The Caribb	Oceana	Total
Low Income	59	16	8	15	8	6	112
Floating Income	4	2	8	5	4	2	25
High Income	8	7	26	0	7	2	50
Total	**71**	**25**	**42**	**20**	**19**	**10**	**187**

The potential of adding low income customer type will allow the expansion of the market to increase from 75 customers in Limited 2010 Business Strategy to 187 customers in Expanded 2011 Business Strategy. Africa and the Middle East have the greatest expansion of customers, going from 12 customers in 2010 to 71 customers in 2011.

Table 3.11 describes Lifescan vial demand to each of these six regions. The vial demands are what Lifescans' manufacturing system must produce to obtain its current market share percentage in these regions.

Table 3.11 Lifescan Vial Demand

Customer Type	Africa & the Middle East	Asia	Europe	Latin America	North America & the	Oceana	Total
Low Income	36,441,443	92,538,279	5,093,775	6,998,765	1,496,818	51,475	142,620,555
Floating Income	5,571,081	2,580,923	12,560,761	10,215,015	212,248	5,984	31,146,012
High Income	7,689,455	15,386,344	24,084,726	0	43,616,242	2,067,798	92,844,565
Total	49,701,979	110,505,546	41,739,262	17,213,780	45,325,308	2,125,257	266,611,132

Table 3.12 describes Lifescan price/vial allocation to each region and each customer type based on maximum, minimum, and average price for customers in a particular region.

Table 3.12 Lifescan Customer Type Price

Lifescan Max, Min & Average Prices for Customer Type																		
Customer Type	Africa & the Middle East			Asia			Europe			Latin America			North America & The Caribb			Oceana		
	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average
Low Income	$17.20	$7.20	$7.74	$7.20	$7.20	$7.20	$9.06	$7.20	$7.72	$25.18	$7.20	$13.05	$7.20	$7.20	$7.20	$7.20	$7.20	$7.20
Floating Income	$23.78	$7.20	$11.35	$14.30	$7.20	$10.75	$16.52	$7.20	$12.03	$28.62	$7.83	$20.58	$10.10	$7.20	$8.39	$12.99	$7.20	$10.10
High Income	$30.00	$7.20	$14.66	$30.00	$16.90	$24.51	$30.00	$12.58	$26.54	$0.00	$0.00	$0.00	$30.00	$9.59	$17.67	$23.75	$13.84	$18.79

Adding an additional low income markets will increas the global market by 112 customers, more than double Lifescan vial demand allocation to its customers, while still keeping customer prices within the upper and lower price bounds. Table 3.13 describes the potential 2011 global market revenue along with Lifescan's global market revenue and its global market share percentage. Global market revenue, Lifescan revenue of world market and Lifescan market share percentage is based on the same calculation as in Limited 2010 Business Strategy.

Table 3.13 Global and Lifescan Market Revenue

Region	Potentail Global Market Revenue	Lifescan Revenue of World Market	Lifescan Market Share % based on World Market
Africa & the Middle East	1,194,240,000	378,311,456	2.92%
Asia	4,058,150,000	1,282,635,305	9.90%
Europe	3,410,220,000	833,850,754	6.44%
Latin America	1,066,760,000	316,230,400	2.44%
North America & The Caribb	3,042,910,000	945,894,176	7.30%
Oceana	177,850,000	45,595,340	0.35%
Total	12,950,130,000	3,802,517,431	29.36%

Table 3.14 compares both global and Lifescan market analysis for Limited 2010 Business Strategy and the potential 2011 Extended Business Strategy. The result of adding an additional customer type to the global market could potentially increase the global market by 45.77%. If Lifescan were to add an additional manufacturing facility in Asia to satisfy 35% of the total demand for a low income customers and still obtaining the required rate of return then Lifescan yearly revenue could increase by 59.81%. Expanding the market could potentially increase Lifescan global market percentage by 9.63% to a global market share percentage value of 29.36%. Expanded 2011 Business Strategy potential market revenue gain for North America and the Caribbean's, Europe, and Oceana is very small because these regions do not have high amounts of low income customers. These regions will drop in terms of global market share because a majority of the demand for these regions was meant in Limited 2010 Business Strategy. Lifescan and its competitors will not see the "Boom" in these regions as they will see in the other three regions so North America and the Caribbean's and Europe will not be the majority revenue producing countries anymore. The 2011 blood sugar strip global market will enter into a globalization phase where low income customers could generate more revenue than high income customers. Due to the increase of demand in these regions, Lifescan's market share percentage may decrease because of a rapid increase in low income customers.

Table 3.14 Comparison of 2010 Global Market and Potential 2011 Global Market

Region	2010 Global Market Revenue	2011 Potential Global Market Revenue	Global Revenue increase % from 2010 to 2011	2010 Lifescan Revenue of World Market	2011 Lifescan Revenue of World Market	Lifescan Revenue increase % from 2010 to	2010 Lifescan Market Share based on	2011 Lifescan Market Share based on	Lifescan Market Share % from 2010 to
Africa & Middle East	$ 420,260,000	$ 1,192,210,000	183.68%	$ 107,418,456	$ 377,600,956	251.52%	1.21%	2.92%	141.32%
Asia	$ 1,436,050,000	$ 4,058,150,000	182.59%	$ 364,900,305	$ 1,282,635,305	251.50%	4.11%	9.91%	141.12%
Europe	$ 3,237,860,000	$ 3,410,220,000	5.32%	$ 773,524,754	$ 833,850,754	7.80%	8.71%	6.44%	-26.06%
Latin America	$ 605,250,000	$ 1,066,760,000	76.25%	$ 154,701,900	$ 316,230,400	104.41%	1.74%	2.44%	40.23%
North America & The Caribb	$ 3,008,190,000	$ 3,042,910,000	1.15%	$ 933,742,176	$ 945,894,176	1.30%	10.51%	7.31%	-30.45%
Oceana	$ 176,400,000	$ 177,850,000	0.82%	$ 45,087,840	$ 45,595,340	1.13%	0.51%	0.35%	-31.37%
Total	$ 8,884,010,000	$ 12,948,100,000	45.75%	$ 2,379,375,431	$ 3,801,806,931	59.78%	26.79%	29.37%	9.63%

4 Manufacturing System Design

Demand is how many products the customer intends to purchase at a particular price. Demand creates an input for the manufacturing system, but can the manufacturing system manufacture the desired demand? This chapter describes how and if the demand can be met by the manufacturing system. Both the Puerto Rico and the China manufacturing facilities have different demand allocations and different manufacturing facility capacities. Creating an optimal manufacturing system is based on the number of shifts, number of machines, number of workers, number of manufacturing cells, utilization of those cells, demand coverage, etc. to maximize the efficiency and minimizing the variable cost to manufacture products. Figure 4.1 displays the breakdown for Chapter 4.

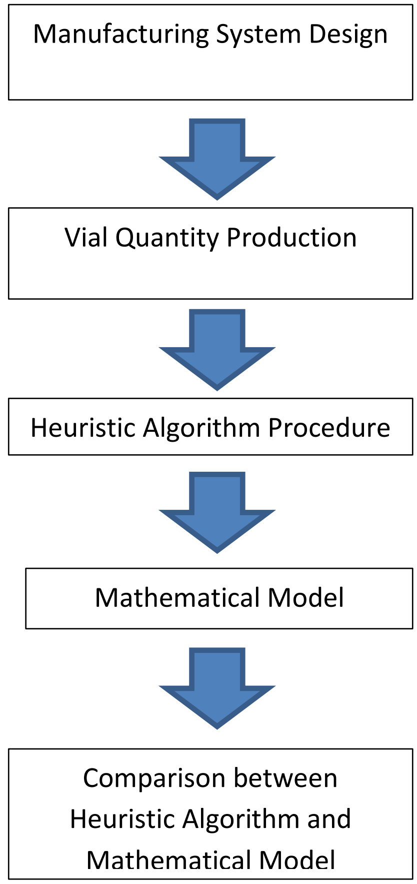

Figure 4.1 Manufacturing System Design Loop

4.1 Part Family

Lifescan's manufacturing system is broken down into five different family types; resulting in a system that produces 36 different products. Family type 1 contains products 1-11, family type 2 contains products 12-24, family type 3 contains products 25-32, family type 4 contains product 33, and family type 5 contains products 34-36. The major different is in the amount of vials that each family type consist of, considering that each vial contains 25 individual strips. Products 1-11 contain only one vial (25 strips), products 12-32 contain two vials (50 strips), and products 33-36 contain four vials (100 strips) as shown in Table 4.1. Different quantities of vials between each family type affect the packaging operations. Products 33-36 packaging line waits until four vials are ready to begin packaging whereas products 1-11 starts packaging once one vial from family one is manufactured.

Table 4.1 Part-Family Matrix

Family	Products	Vial Content
F_1	P1-P11	1 Vial
F_2	P12-P24	2 Vials
F_3	P25-P32	2 Vials
F_4	P33	4 Vials
F_5	P34-P36	4 Vials

According to Ates (2013) family type 1 needs 1 Subassembly (S), 1 Box (B1), 1 Label (L) and 1 Insert (I); Family type 2 needs 2 Subassemblies (S), 1 Box (B2), 1 Label (L) and 1 Insert (I); Family type 3 requires 2 Subassembly (S), 1 Box (B3), 1 Label (L), 1 Insert (I) and 1 Tag (T); Family type 4 needs 4 Subassembly (S), 1 Box (B4), 1 Label (L) and 1 Insert (I); Family type 5 requires 4 Subassembly (S), 1 Box (B5), 1 Label (L), 1 Insert (I) and 1 Tag (T).

4.2 Lifescan Manufacturing System Design

Lifescan's manufacturing system uses a two stage connected cellular system approach. Stage one is fabrication; this is where the products are manufactured, as described in section 4.2.1. Stage two is packaging; this is where the vials are placed together to form a product, as described in section 4.2.2. Cellular system approach described as a manufacturing cell produces a vial then it will first fabricate the product and then package the vials into in a continuous fashion.

4.2.1 Fabrication Operations

The fabrication operation is where the vials and three subassemblies are manufactured. According to Ates (2013), three operations used in fabrication are described below:

Lamination (Operation 1): A long plastic film is developed from rolling a thin paper film of plasma to a harder surface.

Slicing and Bottling (Operation 2): Plastic film (from operation one) is sliced and later vials are filled with test strips.

Capping (Operation 3): Test strips produced and bottled to complete the vial in operation 2 are capped, forming a vial (25 strips).

Ates' (2013) study uses a manufacturing system that runs on the *Fast* operational speed. The fast manufacturing system has faster processing times and this is achieved either by using more machines and/or increased level of manufacturing technology. Tables 4.2-4.3 below show the number of operators, number of machines, and the processing rates for the fabrication operations.

Table 4.2 Fabrication Operations Limited 2010 Production Rates

Fabrication Operation Production Rates				
Family Type	Opr 1 (vials/min)	Opr 2 (vials/min)	Opr 3 (vials/min)	Bottleneck (vials/min)
1	120	114	123	114
2	120	114	123	114
3	120	114	123	114
4	120	114	123	114
5	120	114	123	114

Table 4.3 Fabrication Operations Limited 2010 Number of Machines

	Fabrication Operation Number of Machines			
Family Type	Opr1	Opr2	Opr3	Total
1	1	4	1	6
2	1	4	1	6
3	1	4	1	6
4	1	4	1	6
5	1	4	1	6

Table 4.4 Fabrication Operations Limited 2010 Number of Operators

	Fabrication Operation Number of Operators			
Family Type	Opr1	Opr2	Opr3	Total
1	1	4	1	6
2	1	4	1	6
3	1	4	1	6
4	1	4	1	6
5	1	4	1	6

Fabrication operations are described by production rate (vials/min). From Table 4.2, Operation 2 has the lowest production rate and therefore it is considered the bottleneck operation of the system. All three operations are the same for all five family types. Number of workers and number of machines are described in section 4.2.2. This study expands upon Ates (2013) manufacturing system and adds machines to potential bottleneck operations. Table 4.4, is the new processing times for each family operation for fabrication. Additional machines and operators were added to operation 2 to increase the production level. This increases the bottleneck production rate; from 114 vials/min to 120 vials/min for all family types.

Table 4.5 Fabrication Operations Expanded 2011 Production Rates

Fabrication Operation Production Rates				
Family Type	Opr 1 (vials/min)	Opr 2 (vials/min)	Opr 3 (vials/min)	Bottleneck (vials/min)
1	120	143	123	120
2	120	143	123	120
3	120	143	123	120
4	120	143	123	120
5	120	143	123	120

Table 4.6 Fabrication Operations Expanded 2011 Number of Machines

	Fabrication Operation Number of Machines			
Family Type	Opr1	Opr2	Opr3	Total
1	1	5	1	7
2	1	5	1	7
3	1	5	1	7
4	1	5	1	7
5	1	5	1	7

Table 4.7 Fabrication Operations Expanded 2011 Number of Operators

	Fabrication Operation Number of Operators			
Family Type	Opr1	Opr2	Opr3	Total
1	1	5	1	7
2	1	5	1	7
3	1	5	1	7
4	1	5	1	7
5	1	5	1	7

4.2.2 Packaging Operations

The packaging operation is where the vials are packaged together to form products. According to Ates (2013), five operations are used in packaging are described below:

In the packaging operations, all of 36 of the products that are manufactured in the fabrication stage are sorted and packaged based on their family. To obtain an optimal manufacturing system families are grouped together to create higher utilization and demand capacity along with minimizing the number of manufacturing cells and total machines described later in sections 4.3.2-4.3.4.

<u>Feeding (Operation 4):</u> Vials are moved from the fabrication area to the packaging area.

<u>Labeling (Operation 5):</u> Labels are added to the vial bottles based on product characteristics

<u>Assembling (Operation 6):</u> four operations are performed and are assembled by either operators or machines:

1) Assemble (Operation 6a): The boxes are assembled to get the rectangular prism shape.

2) Vial Insertion (Operation 6b): The vials are placed into the boxes.

3) Instructional Manual Insertion (Operation 6c): The instruction manuals are placed into the boxes.

4) Closing boxes (Operation 6d): The boxes are closed.

<u>Sealing (Operation 7):</u> Boxes are sealed

<u>Bar Coding (Operation 8):</u> Label is added to the outside of the box

<u>Tagging (Operation 9):</u> Anti-theft tags are added to the inner side of the product boxes.

Tables 4.8-4.10 below show the number of operators, number of machines, and the processing rates for the packaging operations. Operations 4-9 are used in the packaging

phase of the manufacturing system. Unlike fabrication, packaging has different operation requirements for each family.

Table 4.8 Packaging Operations Limited 2010 Processing Times

	Packaging Operation Processing Times							
Family Type	Opr4 (vials/min)	Opr5 (vials/min)	Opr6auto (vials/min)	Opr6man (vials/min)	Opr7 (vials/min)	Opr8 (vials/min)	Opr9 (vials/min)	Bottleneck (vials/min)
1	160	135	80	NA	150	150	NA	80
2	160	135	80	NA	150	150	NA	80
3	160	135	80	NA	150	150	60	60
4	160	135	NA	80	150	150	NA	80
5	160	135	NA	80	150	150	120	80

Table 4.9 Packaging Operations 2010 Number of Machines

	Packaging Operation Number of Machines							
Family Type	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	1	NA	NA	1	1	NA	4
2	1	1	NA	NA	1	1	NA	4
3	1	1	NA	NA	1	1	NA	4
4	1	1	4	NA	1	1	NA	8
5	1	1	4	NA	1	1	NA	8

Table 4.10 Packaging Operations 2010 Number of Operators

	Packaging Operation Number of Operators							
Family Type	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	1	NA	4	1	1	NA	8
2	1	1	NA	4	1	1	NA	8
3	1	1	NA	4	1	1	3	11
4	1	1	4	NA	1	1	NA	8
5	1	1	4	NA	1	1	6	14

Since production rates are not consistent from family to family then all must be analyzed. Operation 6-auto is only presented in family types 4 and 5 and uses machines and operators whereas operation 6-man only uses operators for family types 1, 2, and 3. Bottlenecks are based off of operation 6 for product families 1, 2, 4, and 5 whereas family type 3 bottleneck is operation 9. All family types use a bottleneck rate of 80 except family 3 uses a bottleneck value of 60. The data was used in Ates (2013) manufacturing system design. To expand upon this, resources were added in terms of workers and/or machines to three different operations (Opr6auto, Opr6man, and Opr9). The number of resources was increased from 4 to 6 in operation 6 auto and operation 6 man whereas in family 3 operation 9 the number of resources was increased from 3 to 6. Adding additional resources allows for the manufacturing system to increase its bottleneck operation rates. This resulted in the bottleneck rate being increased from 60 vials/min for family type 3 to 120 vials/min. All family types' bottleneck operations were increased from 80 vials/min to 120 vial/min. Since the manufacturing system operates with a connected manufacturing cell approach the operation with the highest production rate in either the fabrication or packaging will be the bottleneck operation. Adding additional resources resulted in the expansion of manufacturing cells in terms of space requirements, which is not considered in this study. Tables 4.11-4.13 below display the number of operators, number of machines, and the production rates for the package operation under the new 2011 expanded manufacturing system design.

Table 4.11 Packaging Operations 2011 Production Rates

	Packaging Operation Processing Times							
Family Type	Opr4 (vials/min)	Opr5 (vials/min)	Opr6auto (vials/min)	Opr6man (vials/min)	Opr7 (vials/min)	Opr8 (vials/min)	Opr9 (vials/min)	Bottleneck (vials/min)
1	160	135	120	NA	150	150	NA	120
2	160	135	120	NA	150	150	NA	120
3	160	135	120	NA	150	150	120	120
4	160	135	NA	120	150	150	NA	120
5	160	135	NA	120	150	150	120	120

Table 4.12 Packaging Operations 2011 Number of Machines

	Packaging Operation Number of Machines							
Family Type	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	1	NA	NA	1	1	NA	4
2	1	1	NA	NA	1	1	NA	4
3	1	1	NA	NA	1	1	NA	4
4	1	1	6	NA	1	1	NA	10
5	1	1	6	NA	1	1	NA	10

Table 4.13 Packaging Operations 2011 Number of Operators

	Packaging Operation Number of Operators							
Family Type	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	1	NA	6	1	1	NA	10
2	1	1	NA	6	1	1	NA	10
3	1	1	NA	6	1	1	6	16
4	1	1	6	NA	1	1	NA	10
5	1	1	6	NA	1	1	6	16

4.3 Manufacturing System Design Components

Three types of manufacturing cells are used; dedicated manufacturing cells, shared manufacturing cells, and remainder manufacturing cells. Dedicated manufacturing cells use only one family type in that particular manufacturing cell. A dedicated manufacturing cell is declared when a family type has high product demand allowing the manufacturing cell to operate at a high utilization rate. Product demand may not be high enough for a dedicated manufacturing cell so a family type will share a manufacturing cell with another family type; a shared manufacturing cell. This results in the combination of two family types in the same manufacturing cell which operates at or less than 100% manufacturing cell utilization. If production of three or more family types is assigned to a manufacturing cell then the manufacturing cell is called a remainder manufacturing cell. Shared and remainder manufacturing cells can cause lost manufacturing time due to tool changeover, idle workers, idle machines, etc. These factors may affect the utilization of the manufacturing cell, so these manufacturing cells may not operate as efficient as dedicated manufacturing cells. The combination of these three types of manufacturing cells creates the layered cellular structure of the manufacturing system. Family types 1, 2 & 3 operate using 11 total machines whereas family types 4 and 5 operate using 17 total machines as described in section 4.2.1 and 4.2.2. Coverage segments that are based on the demand coverage probability for each family type are grouped together to form the least number of manufacturing cells for the manufacturing system which is described in sections 4.3.2 and 4.3.3.

4.3.1 Vial Quantities Produced by Family

This study groups individual products into two categories; vial production and final product production. Product, in terms of vials, is what Lifescan sells to customers. A product may consist of one, two, or four vials depending on what product it is. Family type 1 contains only one vial, family types 2 and 3 contain two vials, while family types 4 and 5 contain four vials. If a customer purchased a product from family type 4 then the product would contain four vials with each vial containing 25 individual blood sugar strips. Based on Lobo (2006) data, the percentage of the total vials allocated to these five family types can be computed, shown below in Table 4.14. Family type vial percentage is assumed to be consistent for both manufacturing facilities.

Table 4.14 Percentage per Product Family Vial

Family Type	Vial %
1	3.35%
2	16.70%
3	15.37%
4	57.20%
5	7.38%

Allocation of how the Expanded 2011 Business Strategy global market demand is described in Table 4.15. China manufacturing facility will manufacture demand for all low income customers (GDP per capita < \$10,000), Puerto Rico manufacturing facility will manufacture demand for all high income customers (GDP per capita > \$20,000), all other demand or floating customer demand (\$10,000 ≤ GDP per capita ≤ \$20,000) will be allocated using one approach; 1) fifty percentage of the floating demand goes to both of the manufacturing plants.

Table 4.15 Part-Family Matrix Expanded 2011 Manufacturing Facility

	Puerto Rico Manufacturing Facility		China Manufacturing Facility		Floating Manufacturing Facility	
Family Type	Number of Product	Number of Vials	Number of Product	Number of Vials	Number of Product	Number of Vials
Family 1	3,106,943	3,106,943	4,772,642	4,772,642	1,042,268	1,042,268
Family 2	7,752,896	15,505,792	11,909,392	23,818,784	2,600,818	5,201,635
Family 3	7,133,260	14,266,520	10,957,556	21,915,112	2,392,952	4,785,904
Family 4	13,277,908	53,111,631	20,396,483	81,585,931	4,454,261	17,817,042
Family 5	1,713,420	6,853,679	2,632,021	10,528,086	574,791	2,299,163
Total	**32,984,426**	**92,844,565**	**50,668,094**	**142,620,555**	**11,065,089**	**31,146,012**

The vial quantities are based off many factors resolved from total revenue market data from the year 2011, as described in Chapter 3. These are forecasted demands based on Equation 3.3. Table 4.16, shows the quantities of each manufacturing facility with their floating demand allocations to each manufacturing facility.

Table 4.16 Expanded 2011 Manufacturing Facility + 50% Floating Demand

Allocation of Floating Vial Demand				
	Puerto Rico + 50% Floating		Asia + 50% Floating	
Family Type	Product	Vial	Product	Vial
Family 1	3,628,077	3,628,077	5,293,776	5,293,776
Family 2	9,053,305	18,106,609	13,209,801	26,419,601
Family 3	8,329,736	16,659,473	12,154,032	24,308,064
Family 4	15,505,038	62,020,152	22,623,613	90,494,452
Family 5	2,000,815	8,003,261	2,919,417	11,677,667
Total	38,516,971	108,417,571	56,200,639	158,193,561

Allocation of floating quantitates along with individual manufacturing plant allocation quantities will be used for the heuristic algorithm study, the mathematical model and the Arena simulation model, described later in the study.

4.3.2 Mean Capacity Requirements

Expanded 2011 Business Strategy manufacturing system design is based on demand allocations. Demand allocations are based on two different types of demand; Deterministic demand and uncertain demand. Deterministic demand is described as when demand is known or can easily be calculated with little or no variation. However, many products and industries have uncertain demand based on many factors throughout the year. This leads to a probabilistic demand approach that allocates percentages to the amount of demand that is covered at the time period. This study uses a probabilistic demand approach assumed to have a normal distribution with the quantities in the above Table 4.17. A standard deviation was randomly chosen between a range of 20%-25% of the mean demand for each family type. Tables 4.17 and 4.18 below display mean demand and the generated standard deviation along with demand allocation + 50% of floating demand to each manufacturing facility.

Table 4.17 Expanded 2011 Business Strategy China Capacity Hour Requirements

	China Manufacturing Facility: Total Demand			**China Manufacturing Facility: Total hours to Manufacture Mean Demand Vials**		
Family Type	Mean Demand	Standard Deviation of Demand	Variance of Demand	Mean Capacity Req.	Standard Deviation of Capacity Req.	Variance of Capacity Req.
1	5,293,776	1,323,444	1,751,504,106,977	735	184	33,787
2	26,419,601	6,604,900	43,624,708,935,334	3,669	917	841,526
3	24,308,064	6,077,016	36,960,124,286,794	3,376	844	712,387
4	90,494,452	19,908,780	396,359,501,561,289	12,569	2,765	7,645,824
5	11,677,667	2,685,863	7,213,862,194,249	1,622	373	139,156

Table 4.18 Expanded 2011 Business Strategy Puerto Rico Capacity Hour Requirements

	Puerto Rico Manufacturing Facility: Total Demand			**Puerto Rico Manufacturing Facility: Total hours to Manufacture Mean Demand Vials**		
Family Type	Mean Demand	Standard Deviation of Demand	Variance of Demand	Mean Capacity Req.	Standard Deviation of Capacity Req.	Variance of Capacity Req.
1	3,628,077	870,738	758,185,318,232	504	121	14,625
2	18,106,609	4,526,652	20,490,581,653,130	2,515	629	395,266
3	16,659,473	3,831,679	14,681,761,613,966	2,314	532	283,213
4	62,020,152	14,264,635	203,479,812,254,064	8,614	1,981	3,925,151
5	8,003,261	1,680,685	2,824,701,128,644	1,112	233	54,489

Below are the equations used to calculate the Capacity Requirements, which are based on previous calculations for mean demand and standard deviation. Mean capacity requirement for the families is calculated by equation 4.1 as defined by Maddisetty (2005) and other equations are from Ates (2013) study.

$$\boldsymbol{MCR\ (in\ Hours) = Mean_{Demand} * \frac{Bottleneck\ Processing\ Time}{60}}\ \text{(min)} \qquad \textbf{(Equation 4.1)}$$

$$\boldsymbol{Variance_{Capacity}(in\ Hours) = Variance_{Demand} * \frac{Bottleneck\ Processing\ Time^2}{60^2}}\ \text{(min)}$$

(Equation 4.2)

$$\boldsymbol{Variance_{Demand}\ (in\ Hours) = Standard\ Deviation^2_{Demand}} \qquad \textbf{(Equation 4.3)}$$

$$\boldsymbol{Standard\ Deviation_{Capacity} = \sqrt{Variance_{Capacity}}} \qquad \textbf{(Equation 4.4)}$$

Mean Capacity calculates the amount of hours that are needed for the manufacturing system to produce the desired demand. This study allocates demand distribution based on demand coverage probabilities.

4.3.3 Demand Coverage Probabilities (DCP)

A demand coverage probability (DCP) is based on the previous discussion about what percentage of the total demand each plant will produce. DCP allocates a probability percentage to a given manufacturing cell to cover demand for a particular family type. Manufacturing cell can operate using 2000 hours (1 shift), 4000 hours (2 shifts), and 6000 hours (3 shifts) machining hours per year. Table 4.19 describe cumulative demand for the China manufacturing facility plus of the 50% floating demand, if all family types operate under 4000 machining hours (2 shifts). A NORMSDIST function in excel was used to find the (DCP).

$$\boldsymbol{Demand\ Coverage\ Probability_i = NORMSDIST\ (\frac{S*I-\mu_C}{\sigma_C})} \qquad \textbf{(Equation 4.5)}$$

Manufacturing hours (S) is assumed to be either 2000, 4000, or 6000 hours/year for 1 shift, 2 shifts, or 3 shifts, respectively. Example below uses family type 3 operating under 2-shift from China manufacturing plant plus 50% floating, using the mean capacity information.

$$Demand\ Coverage\ Probability_{First\ Cell_{Family\ 3}} = NORMSDIST(\frac{4000*1-3376}{844}) = 0.770$$

Demand Coverage Probability equation 4.5 determines the probability that if there is only 1 manufacturing cell is established for family type 3 then there is a 77.0% probability that all demand will be satisfied for the particular year if the manufacturing system operates with only one manufacturing cell for family type 3. This equation is used for all manufacturing cells and family types until the family type reaches 100% demand coverage probability. This would allow for 100% of the demand to be manufactured which result in all customers demand being satisfed. Once 100% demand coverage probability is reached no new additional manufacturing cells are needed.

Table 4.19 Expanded 2011 Business Strategy China Demand Coverage

China Manufacturing Facility: Demand Coverage Probability for 4000 manufacturing hours								
Family Type	Manufacturing Cell 1	Manufacturing Cell 2	Manufacturing Cell 3	Manufacturing Cell 4	Manufacturing Cell 5	Manufacturing Cell 6	Manufacturing Cell 7	Manufacturing Cell 8
1	100.0%	NA	NA	NA	NA	NA	NA	NA
2	64.1%	100.0%	NA	NA	NA	NA	NA	NA
3	77.0%	100.0%	NA	NA	NA	NA	NA	NA
4	0.1%	4.9%	41.9%	89.3%	99.6%	100.0%	NA	NA
5	100.0%	NA	NA	NA	NA	NA	NA	NA
*NA: Manufacturing cell is not needed								

4.3.4 Expected Cell Utilization

The probability calculations in the previous section correspond to the likelihood that a manufacturing cell will produce all of the intended demand. The expected manufacturing cell formulation, proposed by Suer and Ortega (Suer and Ortega, 1994) is presented in equation 4.6:

$$E(C = X) = P(CR > C) * PU_1 + P(X - 1 \leq CR \leq C) * PU_2 + P(CR < X - 1) * PU_3$$

(Equation 4.6)

Where

E(C=X) Expected manufacturing cell utilization for the Xth cell assigned to a family

P(CR>X) Probability that the number of manufacturing cells required (CR) is greater than X

PU_1 Percent utilization of manufacturing cell X when CR>X

P(X-1≤CR≤X) Probability that the number of manufacturing cells required falls within X-1 and X

PU_2 Percent utilization of manufacturing cell X when CR<X-1

P(CR<X-1) Percent utilization of manufacturing cell X where CR<X-1

PU_3 Percent utilization of manufacturing cell X when CR < X-1

PU_2 is calculated by solving the equation 4.7 below

$$\boldsymbol{PU_2} = \int_{\boldsymbol{4000(X-1)}}^{\boldsymbol{4000(X)}} \frac{\boldsymbol{y * f(y)}}{\boldsymbol{4000 * A}} \boldsymbol{dy} - (\boldsymbol{X - 1})$$ **(Equation 4.7)**

Where

f(y) Probability density for the number of manufacturing cells required

Y Random variable representing the number of manufacturing cells required

A Probability that manufacturing cells required is between X-1 and X

The probability density function f(y) can follow any kind of distribution but for this study it uses a normal distribution as shown:

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2 \frac{1}{2\sigma^2}}$$

$$PU_2 = \int_{4000(1-1)}^{4000*1} \frac{y * f(y)}{4000 * 1} dy - (1-1) = 0.18375$$

Table 4.20 Expanded 2011 Business Strategy China Manufacturing Cell Utilization

	China Manufacturing Facility: Expected Manufacturing Cell Utilization for 4000 hours									
Family Type	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
1	18.4%	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	86.2%	5.6%	NA	NA	NA	NA	NA	NA	NA	NA
3	81.6%	2.8%	NA	NA	NA	NA	NA	NA	NA	NA
4	100.0%	100.0%	98.6%	80.3%	31.8%	3.0%	NA	NA	NA	NA
5	40.6%	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.19 calculates the probability that all of the demand will be manufactured for a certain number of manufacturing cells with a specific number of manufacturing hours. The calculation does not cover the utilization for a manufacturing cell. Efficient manufacturing systems run from

manufacturing cells having high utilization rates so resources such as workers and machines stay busy. Expected manufacturing cell utilization calculations are described in table 4.20. As discussed in section 3.3 manufacturing cells can be a combination of one or multiple family types.

4.3.5 Family Similarity

Once utilization and demand coverage probabilities are determined for manufacturing cells then grouping must be performed. A family type similarity matrix is used to group families that have similar attributes together in table 4.21. In this study Jaccard's coefficient was used and covered by Ates (2013) study. The calculations were based on the number of common machines divided by the maximum number of machines of the two families.

Table 4.21 Family Similarity Matrix

Family Similarity Matrix					
	Family 1	Family 2	Family 3	Family 4	Family 5
Family 1	-	1.00	0.89	0.78	0.70
Family 2	1.00	-	0.89	0.78	0.70
Family 3	0.89	0.89	-	0.70	0.80
Family 4	0.78	0.78	0.70	-	0.89
Family 5	0.70	0.70	0.80	0.89	-

Similarity matrix allows common families to be grouped together to allow for a decrease in number of workers, number of machines, etc. Grouping cells together allows cells to have utilization close/at the desired amount. With utilization at this point then workers/machines will stay busy and produce their optimal amount of production per cell. This allows the manufacturing system to be closer/at optimal efficiency level that the system can handle. A preexisting mathematical model by Maddisetty (2005) is expanded upon and used later in this chapter to find an optimal solution for grouping remainder and shared cells together to minimize the number of manufacturing cells.

4.3.6 Cell-based Machine and Operator Requirement

Number of machines and operators is based on the number of manufacturing cells and how the manufacturing cells are grouped together. Two different types of manufacturing grouping were analyzed for Lifescan manufacturing system; 1) Heuristic Algorithm by selecting manufacturing cells and grouping them together to minimize number of manufacturing cells based on expected manufacturing cell utilization, demand coverage probabilities with different shift types which is described in section 4.3.3 and 2) modeling the manufacturing system using mathematical modeling in a program called OPL to minimize the manufacturing system cost based on manufacturing cell utilization, demand coverage probability with different shift types which is described in section 4.4.2.1. Both types of grouping procedures have an objection function to minimize the number of manufacturing cells in the manufacturing system.

4.4 Cellular Manufacturing Layout Requirements

Lifescan's manufacturing systems allocates manufacturing cell utilization and family type demand probabilities that 100% of the demand will be manufactured in either the China manufacturing facility and/or the Puerto Rico manufacturing facility. This section describes the requirements for worker and machines that each family requires for the products to be produced. As discussed before, manufacturing cells that are categorized as shared or remainder will need the requirements to manufacture all of the family types that the manufacturing cell is dedicated to. Allocating the amount of machines, workers, and manufacturing cell grouping will produce a cost amount for each manufacturing cell and for the entire manufacturing system.

4.4.1 Cell-based Machine and Operator Requirement Heuristic Algorithm

Heuristic Algorithm manufacturing cell grouping was done based on manufacturing cell utilizations and that the notion that each family type demand coverage probability is 100%. Each manufacturing cell could operate at or less than a utilization of 100% or overtime can be used if capacity is not sufficient. This study uses the notation that no overtime is used. Manufacturing cells are made up of coverage segments from different family types. A manufacturing cell can only be made up of one coverage segment from an individual family type, so no duplication of the coverage segments from the same family type in one manufacturing cell. Manufacturing cells will be made up of only the same shift types, so a coverage segment operating at shift type 1 will not be in the same manufacturing cells as a coverage segment with a shift type 2. Manufacturing cells can be grouped using three different shift types (Shift type 1: 8 manufacturing hours/day, shift type 2: 16 manufacturing hours/day, or shift type 3: 24 hours/day). Family types are broken down into different option types. The options have a combination of shift type 1, shift type 2, or shift type 3. Based on the capacity of the manufacturing system, different family type options will be selected. Only one option will be used for each family type. Grouping of manufacturing cells based on the heuristic algorithm is based on the China manufacturing facility + 50% of floating demand. Table 4.22 describe the manufacturing cell formulation which is based on how the manufacturing cells are grouped together to minimize the total number of manufacturing cells in the manufacturing system while obtaining a high utilization amount for each manufacturing cell. The number of options for a family type is determined by the number of different combinations that the demand coverage probability can be manufactured at. Family types with more demand will require more options because there are more variations for the utilizations of manufacturing cells with the maximum number of manufacturing cells for a single family type is 16; family type 4. Table 4.22 displays the family types, options, and the shift type combinations: NA refers to the fact that the manufacturing cell is not needed to manufacture the desired demand coverage probability.

Table 4.22 Expanded 2011 Business Strategy China Facility Shift Allocation

China Manufacturing Faciliy: Shift Allocation based on option number											
Family Type	**Option**	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**Cell 7**	**Cell 8**	**Cell 9**	**Cell 10**
Family 1	1	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA	NA
Family 2	1	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA
	3	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	4	Shift 2	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	5	Shift 2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
Family 3	1	Shift 1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA
	3	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	4	Shift 2	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	5	Shift 2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
Family 4	1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1
	2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	NA
	3	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1	NA
	4	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1	Shift 1	NA
	5	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	NA	NA
	6	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1	NA	NA
	7	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1	Shift 1	NA	NA
	8	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	NA	NA	NA
	9	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 1	NA	NA	NA
	10	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	NA	NA	NA	NA
	11	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2	NA	NA	NA	NA
	12	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	NA
	13	Shift 2	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA
	14	Shift 2	Shift 2	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA	NA
	15	Shift 2	Shift 2	Shift 2	Shift 2	Shift 1	Shift 1	NA	NA	NA	NA
	16	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2		NA	NA	NA	NA
Family 5	1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	3	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA	NA

4.4.2 Heuristic Steps for China Manufacturing Facility + 50% of Floating Demand

1) Select an appropriate shift type for maximum manufacturing cell allocation for the manufacturing system (This example uses a 16 hour shift for Asia manufacturing facility + 50% of floating demand)
    a. 8 hour; 1 shift; 2000 yearly manufacturing hours
    b. 16 hour; 2 shifts; 4000 yearly manufacturing hours
    c. 24 hour: 3 shifts; 6000 yearly manufacturing hours
2) Rank product families in demand allocation based on the quantity of vials produced
3) Demand Rank

Table 4.23 Demand Rank

Demand Rank	Family Type	Number of Options
1	4	16
2	2	5
3	3	5
4	5	3
5	1	2

4) Start with family 4, and go to the last option, option 16. Create 2 shift manufacturing cells so 5 manufacturing cells will be created.
5) Rearrange the manufacturing cells so that the least amount of utilization is the first manufacturing cell. Add the next product family. Product family 2 is selected
6) Start with the last option and coverage segment 1. Add to the least utilization manufacturing cell if it does not exceed 100%. If it exceeds 100% then go to

option – 1. Continue to do this until the shift type changes and create a new manufacturing cell for shift 1.

7) With the current option go to coverage segment 2 and if it has a shift type 2 then add to shift type 2 manufacturing cells.

8) Continue until all coverage segments for each family along with all families. Results are shown below for current manufacturing

An example is described in the following example with tables 4.24- 4.29. This is just an example to describe the heuristic algorithm and has nothing to do with Lifescan Table 4.24 displays the demand for each of the three vials.

Table 4.24 Demand Rank Example

Vial Type	Demand	Rank
Vial 1	100	3
Vial 2	200	2
Vial 3	300	1

Table 4.25 displays the utilization for individual coverage segments for each of the three vials.

Table 4.25 Data Example

Vial Type	Option	CS 1	CS 2
Vial 1	1	60%	
	2	25%	
Vial 2	1	90%	
	2	50%	
Vial 3	1	99%	99%
	2	90%	50%
2 Shift Cells		1 Shift Cells	

Table 4.26 displays the selection process of vial 3, because this vial has the most demand. The last option is selected, which is option 2.

Table 4.26 Vial 3 Example

		2 Shift Cells	
Vial Type	Option	Cell 1	Cell 2
Vial 3	2	90%	50%
Total		90%	50%

Table 4.27 displays the rearrangement of manufacturing cells based on minimum utilization.

Table 4.27 Rearrange Example

		2 Shift Cells	
Vial Type	Option	Cell 1	Cell 2
Vial 3	2	50%	90%
Total		50%	90%

Table 4.28 displays the addition of vial 2 into the manufacturing system. First the last coverage segment is selected, which is option 2. Coverage segment 1 is added to manufacturing cell 1 if the utilization does not exceed 100%.

Table 4.28 Vial 2 Example

		2 Shift Cells	
Vial Type	Option	Cell 1	Cell 2
Vial 3	2	50%	90%
Vial 2	2	50%	
Total		100%	90%

Table 4.29 displays the rearrangement of manufacturing cells based on minimum utilization.

Table 4.29 Rearrange 2 Example

		2 Shift Cells	
Vial Type	Option	Cell 1	Cell 2
Vial 3	2	90%	50%
Vial 2	2		50%
Total		90%	100%

Table 4.30 displays the addition of vial 1 into the manufacturing system. First the last coverage segment is selected, which is option 2. Since option 2, coverage segment 1 cannot be added to any of the existing manufacturing cells then option 1 is selected. Since option 1 contains only 1 shift manufacturing cells, a new manufacturing cell is created for 1 shift. This is the final manufacturing system design for the heuristic algorithm example.

Table 4.30 All Vial Example

		2 Shift Cells		1 Shift Cell
Vial Type	Option	Cell 1	Cell 2	
Vial 3	2	90%	50%	
Vial 2	2		50%	
Vial 1	1			60%
Total		90%	100%	60%

Table 4.31 displays the selected options for each family that were selected based on the heuristic algorithm. Highlighted options are the selected options.

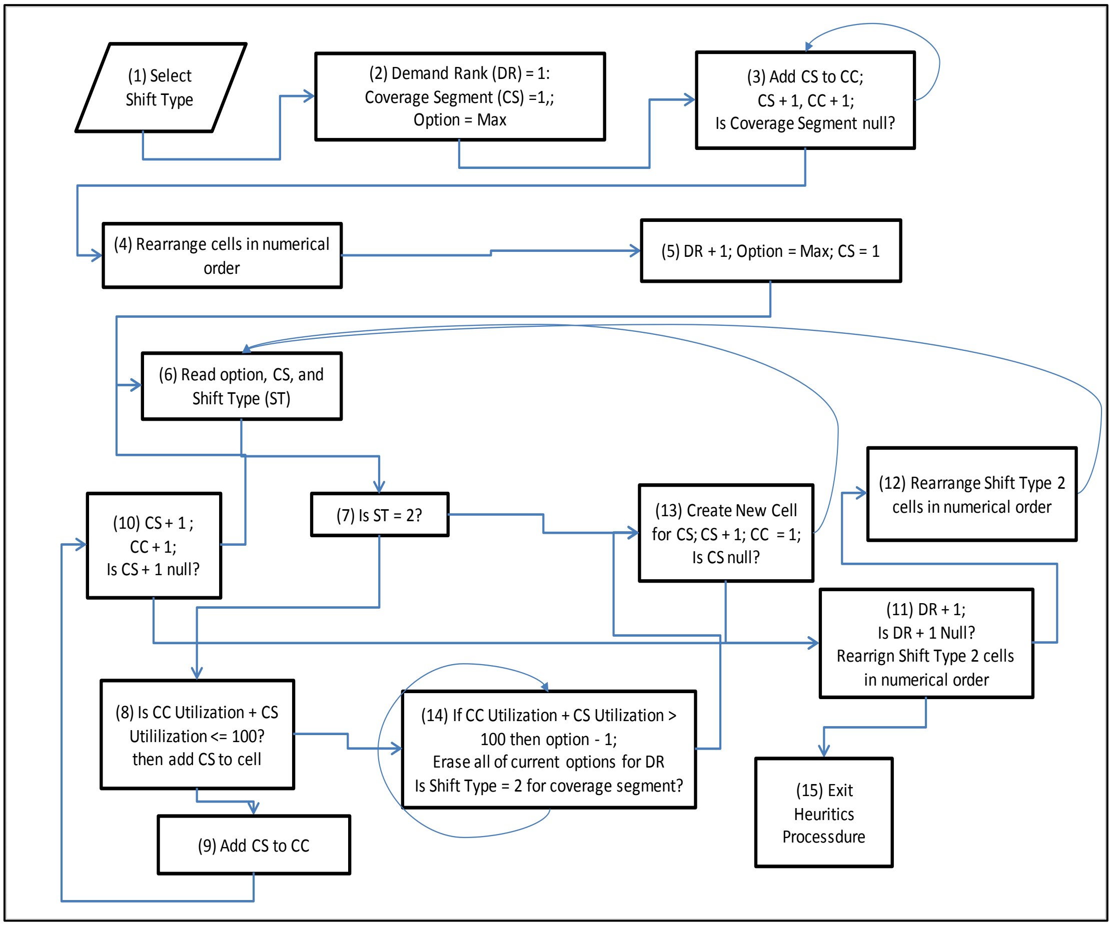

Figure 4.2 Heuristic Algorithm

Table 4.31 Shift Allocation

China Manufacturing Faciliy: Shift Allocation based on option number											
Family Type	Option	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
Family 1	1	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA	NA
Family 2	1	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA
	3	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	4	Shift 2	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	5	Shift 2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
Family 3	1	Shift 1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA
	3	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	4	Shift 2	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	5	Shift 2	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
Family 4	1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1
	2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	NA
	3	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1	NA
	4	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1	Shift 1	NA
	5	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	NA	NA
	6	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1	NA	NA
	7	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1	Shift 1	NA	NA
	8	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	NA	NA	NA
	9	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 1	NA	NA	NA
	10	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	NA	NA	NA	NA
	11	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2	NA	NA	NA	NA
	12	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	NA
	13	Shift 2	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA
	14	Shift 2	Shift 2	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	NA	NA	NA
	15	Shift 2	Shift 2	Shift 2	Shift 2	Shift 1	Shift 1	NA	NA	NA	NA
	16	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2		NA	NA	NA	NA
Family 5	1	Shift 1	Shift 1	NA	NA	NA	NA	NA	NA	NA	NA
	2	Shift 1	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA
	3	Shift 2	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.32, is the results for each of the seven manufacturing cells. O16F4CS1 for manufacturing cell 1: refers to Option 16, family type 4, and coverage segment 1 from family type 4.

Table 4.32 Manufacturing Cell Allocation

Option Number, Family Number, Coverage Segement Number						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
O16F4CS1	O16F4CS2	O16F4CS3	O16F4CS4	O12F4CS5	O3F3CS1	O2F5CS1
			O5F2CS2	O5F2CS1		
			O3F3CS2			
			O2F5CS2			
			O2F1CS1			

Table 4.33, allocates the total utilization that the manufacturing cell will operate at. The highest manufacturing cell will operate at 100% utilization and the lowest will operate at 80.3%.

Table 4.33 Cell Utilization Results with Heuristic Procedure

Heuristic Algorithm Utilization Totals						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
100.0%	98.6%	80.3%	30.8%	3.0%	99.1%	87.6%
			5.6%	86.2%		
			34.9%			
			2.4%			
			18.4%			
100.0%	98.6%	80.3%	92.0%	89.2%	99.1%	87.6%

Tables 4.34 & 4.35; calculate the number of machines and operators that each manufacturing cell will need to manufacture the desired amount of demand. The number of operators is doubled for shift type 2, since in this study an operator will work only one 8 hour shift. Since operation 9 for family 3 and 5 has 6 operators, then if families 3 and 5 are grouped together in the same manufacturing cell with other family types the number of operators must be accommodated for this operation. The totals are computed using

sections 4.2.1 and 4.2.2. The number of operators is not just multiplying by 2, but looking at the production system for individual machines and operations to figure out the total number of operators.

Table 4.34 Number of Operators

China Manufacturing Facility + 50%: Number of Operators						
16 hours; 2 Shifts Manufacturing Cells ***Must double the amount of operators for 2 shifts**					8 hours; 1 Shift Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
17	17	17	17	17	23	23
			17	17		
			23			
			23			
			17			
34	34	34	58	34	23	23
Total Operators: 240						

Table 4.35 Number of Machines

China Manufacturing Facility + 50%: Number of Machines						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
17	17	17	17	17	11	17
			11	11		
			11			
			17			
			11			
17	17	17	17	17	11	17
Total Machines: 113						

The manufacturing system will operate using 7 manufacturing cells for a total of 113 machines in the system. From section 4.2.1 family types 1-3 operate using 11 machines where family type 4 and 5 operate using 17 machines. From section 4.2.2, family type 1, 2, & 4 operate using 17 operators, family type 3 and 5 operate using 23 operators to fabricate and package a product. If a manufacturing cell operates under shift type 2 then number of operators is doubled and if shift type 3 then number of operators is tripled to account for the additional output. Tables 4.36-4.39 refer to the Expanded 2011 Business Strategy for the Puerto Rico Manufacturing Facility + 50% Floating Demand. All manufacturing cells will operate under 2 shifts or 16 manufacturing hours per day.

Table 4.36 Manufacturing Cell Allocation

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Option, Family Number, Coverage Segment Number			
Cell 1	Cell 2	Cell 3	Cell 4
F4O14CS1	F4O14CS2	F4O14CS3	F4O14CS4
		F2O4CS2	F2O4CS1
		F3O4CS1	F3O4CS2
		F1O2CS1	F5O2CS1

Table 4.37 Manufacturing Cell Utilization

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Manufacturing Cell Utilization			
Cell 1	Cell 2	Cell 3	Cell 4
99.8%	87.1%	27.5%	0.9%
		0.0%	62.8%
		57.9%	0.0%
		12.6%	27.8%
99.8%	87.1%	98.0%	91.5%

Table 4.38 Number of Operators PR Facility

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Total Operators			
16 Hours: 2 Shifts Manufacturing Cells			
Cell 1	Cell 2	Cell 3	Cell 4
17	17	17	17
		17	17
		23	23
		17	23
34	34	58	58
Total Operators: 184			

Table 4.39 Number of Machines PR Facility

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Total Machines			
Cell 1	Cell 2	Cell 3	Cell 4
17	17	17	17
		11	11
		11	11
		11	17
17	17	17	17
Total Machines: 68			

Tables 4.40 – 4.43 refer to the Limited 2010 Business Strategy for the Puerto Rico Manufacturing Facility.

Table 4.40 Manufacturing Cell Allocation

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Option, Family Number, Coverage Segment Number								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
F4O16CS1	F4O16CS2	F4O16CS3	F4O16CS4	F4O16CS5	F4O16CS6	F2O3CS1	F2O3CS2	F5O2CS1
			F3O13CS3	F3O13CS2	F3O13CS1			
			F5O2CS2	F2O3CS3				
			F1O2CS1					

Table 4.41 Manufacturing Cell Utilization

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Manufacturing Cell Utilization								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
0.9998	0.992854	0.9082	0.585373477	0.18495296	0.02214613	0.9969	0.856573	0.8948
			0.0013	0.343815	0.97777			
			0.02937	0.1516				
			0.216					
0.9998	0.992854	0.9082	0.832043477	0.68036796	0.99991613	0.9969	0.856573	0.8948

Table 4.42 Total Number of Operators

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Total Operators								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
17	17	17	17	17	17	17	17	23
			23	23	23			
			23	17				
			17					
34	34	34	58	58	58	17	17	23
Total Operators: 333								

Table 4.43 Total Number of Machines

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Total Machines								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
17	17	17	17	17	17	11	11	17
			11	11	11			
			17	11				
			11					
17	17	17	17	17	17	11	11	17
Total Machines: 141								

4.4.2.1 Mathematical Model (OPL Model)

This study uses a program called OPL to study possible optimization paths for the manufacturing system design. This mathematical model was built to minimize the number of manufacturing cells across multiple shifts. Machine and operator costs are dependent on the shift type, so machines and operators will have different costs if they are operating for one shift, two shifts, or three shifts. The higher the shift type then the more machining hours in a day there will be in a manufacturing cell. This corresponds into more products being manufactured during a day. With manufacturing systems running for longer amounts of time during a day, then fixed costs are decreased on a per product base. Reducing production costs while keeping a certain level of quality will allow Lifescan to enter additional markets while still obtaining their profit margins.

This study advances the complexity of Maddisetty (2005) mathematical model in the area of manufacturing cells operating at longer than 1 shift along with a manufacturing system operating under a multi-shift basis. Multi-shift basis means that a manufacturing system can operate using any combination of shift type 1, shift type 2, or shift type 3.This addition to the model corresponds into additional complexity with an end result of minimizing the total number of manufacturing cells for the manufacturing system. Once the number of manufacturing cells is determined then additional costs can be added.

Tables 4.44 and 4.45 below, display the manufacturing cell utilization, demand coverage probabilities, and the shift type values for an example to be solved in the OPL-CPLEX. The example is based on the Expanded 2011 Business strategy using the China manufacturing facility + 50% floating demand.

Table 4.44 Expected Utilization for Manufacturing Cells

China Manufacturing Faciliy: Expected Manufacturing Cell Utilization											
Family	Option	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
1	1	36.8%	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	18.4%	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	1	99.5%	73.2%	11.4%	0.2%	NA	NA	NA	NA	NA	NA
	2	99.5%	73.2%	5.6%	NA	NA	NA	NA	NA	NA	NA
	3	99.5%	42.4%	NA	NA	NA	NA	NA	NA	NA	NA
	4	86.2%	11.2%	NA	NA	NA	NA	NA	NA	NA	NA
	5	86.2%	5.6%	NA	NA	NA	NA	NA	NA	NA	NA
3	1	99.1%	64.2%	5.5%	NA	NA	NA	NA	NA	NA	NA
	2	99.1%	64.2%	2.8%	NA	NA	NA	NA	NA	NA	NA
	3	99.1%	34.9%	NA	NA	NA	NA	NA	NA	NA	NA
	4	81.6%	5.6%	NA	NA	NA	NA	NA	NA	NA	NA
	5	81.6%	2.8%	NA	NA	NA	NA	NA	NA	NA	NA
4	1	100.0%	100.0%	99.7%	97.5%	89.5%	70.9%	43.8%	20.0%	5.2%	0.7%
	2	100.0%	100.0%	99.7%	97.5%	89.5%	70.9%	43.8%	20.0%	3.0%	NA
	3	100.0%	100.0%	99.7%	97.5%	89.5%	70.9%	43.8%	11.7%	0.7%	NA
	4	100.0%	100.0%	99.7%	97.5%	89.5%	70.9%	31.8%	5.2%	0.7%	NA
	5	100.0%	100.0%	99.7%	97.5%	89.5%	70.9%	31.8%	3.0%	NA	NA
	6	100.0%	100.0%	99.7%	97.5%	89.5%	57.2%	12.3%	0.7%	NA	NA
	7	100.0%	100.0%	99.7%	97.5%	80.3%	31.8%	5.3%	0.7%	NA	NA
	8	100.0%	100.0%	99.7%	97.5%	80.3%	31.8%	3.0%	NA	NA	NA
	9	100.0%	100.0%	99.7%	92.4%	61.3%	14.4%	0.8%	NA	NA	NA
	10	100.0%	100.0%	98.6%	80.3%	31.8%	3.0%	NA	NA	NA	NA
	11	100.0%	99.8%	93.4%	57.2%	12.3%	0.5%	NA	NA	NA	NA
	12	100.0%	98.6%	80.3%	30.8%	3.0%	NA	NA	NA	NA	NA
	13	100.0%	99.7%	97.5%	97.1%	70.8%	43.8%	20.0%	5.2%	0.7%	NA
	14	100.0%	98.7%	89.5%	70.8%	43.8%	20.0%	5.2%	0.7%	NA	NA
	15	100.0%	98.7%	80.3%	43.8%	20.0%	5.2%	0.7%	NA	NA	NA
	16	100.0%	98.7%	80.3%	31.8%	5.2%	0.7%	NA	NA	NA	NA
5	1	87.6%	4.8%	NA	NA	NA	NA	NA	NA	NA	NA
	2	87.6%	2.4%	NA	NA	NA	NA	NA	NA	NA	NA
	3	40.6%	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.45 China Demand Coverage Probability

China Manufacturing Faciliy: Manufacturing Cell Demand Coverage Probability											
Family	Option	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10
1	1	100.0%	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	100.00%	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	1	3.40%	60.63%	99.40%	100.00%	NA	NA	NA	NA	NA	NA
	2	3.40%	60.63%	35.37%	NA	NA	NA	NA	NA	NA	NA
	3	3.40%	94.76%	NA	NA	NA	NA	NA	NA	NA	NA
	4	64.07%	35.93%	NA	NA	NA	NA	NA	NA	NA	NA
	5	64.07%	35.93%	NA	NA	NA	NA	NA	NA	NA	NA
3	1	5.15%	71.86%	22.90%	NA	NA	NA	NA	NA	NA	NA
	2	5.15%	71.86%	22.90%	NA	NA	NA	NA	NA	NA	NA
	3	5.15%	94.76%	NA	NA	NA	NA	NA	NA	NA	NA
	4	77.01%	22.99%	NA	NA	NA	NA	NA	NA	NA	NA
	5	77.01%	22.99%	NA	NA	NA	NA	NA	NA	NA	NA
4	1	0.01%	0.09%	0.78%	4.05%	12.72%	24.21%	27.91%	19.50%	8.26%	2.12%
	2	0.01%	0.09%	0.78%	4.05%	12.72%	24.21%	27.91%	19.50%	10.37%	NA
	3	0.01%	0.09%	0.78%	4.05%	12.72%	24.21%	27.91%	27.76%	2.12%	NA
	4	0.01%	0.09%	0.78%	4.05%	12.72%	24.21%	47.42%	8.26%	2.12%	NA
	5	0.01%	0.09%	0.78%	4.05%	12.72%	24.21%	47.42%	10.37%	NA	NA
	6	0.01%	0.09%	0.78%	4.05%	12.72%	52.12%	27.76%	2.12%	NA	NA
	7	0.01%	0.09%	0.78%	4.05%	36.93%	47.42%	8.26%	2.12%	NA	NA
	8	0.01%	0.09%	0.78%	4.05%	36.93%	47.42%	10.37%	NA	NA	NA
	9	0.01%	0.09%	0.78%	16.77%	52.12%	27.76%	2.44%	NA	NA	NA
	10	0.01%	0.09%	4.83%	36.93%	47.42%	10.37%	NA	NA	NA	NA
	11	0.01%	0.87%	16.77%	52.12%	27.76%	2.12%	NA	NA	NA	NA
	12	0.10%	0.78%	4.05%	12.72%	24.21%	27.91%	19.50%	8.26%	2.47%	NA
	13	0.10%	4.83%	12.72%	24.21%	27.91%	19.50%	8.26%	2.47%	NA	NA
	14	0.10%	4.83%	36.93%	27.91%	19.50%	8.26%	2.47%	NA	NA	NA
	15	0.10%	4.83%	36.93%	47.42%	8.26%	2.46%	NA	NA	NA	NA
	16	0.10%	4.83%	36.93%	47.42%	10.37%	NA	NA	NA	NA	NA
5	1	84.46%	15.54%	NA	NA	NA	NA	NA	NA	NA	NA
	2	84.46%	15.54%	NA	NA	NA	NA	NA	NA	NA	NA
	3	100.00%	NA	NA	NA	NA	NA	NA	NA	NA	NA

Refer to the Appendix B for Standard Puerto Rico manufacturing facility and Expanded 2011 Puerto Rico + 50% floating manufacturing facility.

4.5 OPL CPLEX Mathematical Model

Mathematical modeling is satisfying an objective function subject to multiple constraints. The mathematical model creates a dynamic approach to grouping family types based on characteristics resulting the grouping of high productivity manufacturing cells. Figure 4.3 shows the mathematical model based on its objective function and constraints. Some of these notations are based on Sripathi (2005) mathematical model and some are additional notations.

Notation – The notation used in the model is as follows:

Parameters:

A Maximum number of coverage segments for any option for the entire manufacturing system

D Minimum demand coverage for a manufacturing family

P Number of product families

Q Number of coverage segments for an option; this number should be the same for all families

R Number of manufacturing cells for each shift type

W Number of options for each family; this number should be the same for all families

Indices:

I Index for product family ($i = 1, 2 \ldots p$)

J Index for options ($j = 1, 2 \ldots q$)

K Index for coverage segment ($k = 1, 2 \ldots q$)

KK Index for coverage segment (k = 2, 3 … q)

L Index for manufacturing cells (l = 1, 2 … p)

Model Matrix Components:

$DemCovA_{\boldsymbol{ijk}}$ Demand coverage of shift type 1 for product family 'i' option 'j' and coverage segment 'k'

$DemCovB_{\boldsymbol{ijk}}$ Demand coverage of shift type 2 for product family 'i' option 'j' and coverage segment 'k'

$DemCovC_{ijk}$ Demand coverage of shift type 3 for product family 'i' option 'j' and coverage segment 'k'

$ExpUtilA_{\boldsymbol{ijk}}$ Expected utilization of shift type 1 for product family 'i' option 'j' and coverage segment 'k'

$ExpUtilB_{\boldsymbol{ijk}}$ Expected utilization of shift type 2 for product family 'i' option 'j' and coverage segment 'k'

$ExpUtilC_{\boldsymbol{ijk}}$ Expected utilization of shift type 3 for product family 'i' option 'j' and coverage segment 'k'

Model Boolean Variables:

$Option_{\boldsymbol{ij}}$ Option for product family 'i' and option 'j'

$$\begin{cases} 1; If\ option\ is\ formed \\ \quad 0: otherwise \end{cases}$$

$ShiftA_{\boldsymbol{ijkl}}$ Shift type 1 for product family 'i' option 'j' coverage segment 'k' and manufacturing cell 'l'

$$\begin{cases} 1; If\ product\ family, option, coverage\ segment, \\ manufacturing\ cell\ are\ formed\ for\ shift\ type\ one \\ \quad 0: otherwise \end{cases}$$

$ShiftB_{\boldsymbol{ijkl}}$ Shift type 2 for product family 'i' option 'j' coverage segment 'k' and manufacturing cell 'l'

$$\begin{cases} 1; If\ product\ family, option, coverage\ segment, \\ manufacturing\ cell\ are\ formed\ for\ shift\ type\ two \\ 0: otherwise \end{cases}$$

$ShiftC_{\boldsymbol{ijkl}}$ Shift type 3 for product family 'i' option 'j' coverage segment 'k' and manufacturing cell 'l'

$$\begin{cases} 1; If\ product\ family, option, coverage\ segment, \\ manufacturing\ cell\ are\ formed\ for\ shift\ type\ three \\ 0: otherwise \end{cases}$$

$ShiftACell_{\boldsymbol{l}}$ Shift type 1 for manufacturing cell 'l'

$$\begin{cases} 1: If\ manufacturing\ cells\ are\ formed\ for\ shift\ type\ one \\ 0; otherwise \end{cases}$$

$ShiftBCell_{\boldsymbol{l}}$ Shift type 2 for manufacturing cell 'l'

$$\begin{cases} 1: If\ manufacturing\ cells\ are\ formed\ for\ shift\ type\ two \\ 0; otherwise \end{cases}$$

$ShiftCCell_{\boldsymbol{l}}$ Shift type 3 for manufacturing cell 'l'

$$\begin{cases} 1: If\ manufacturing\ cells\ are\ formed\ for\ shift\ type\ three \\ 0; otherwise \end{cases}$$

Objection Function:

Minimize the number of manufacturing cells **(Equation 4.8)**

Constraints:

Only one option is selected for each product family

1) If an option is selected then all coverage segments are selected, repeated for three different shift types:

a. Shift Type One **(Equation 4.9)**

b. Shift Type Two **(Equation 4.10)**

c. Shift Type Three **(Equation 4.11)**

2) Manufacturing cell utilization does not exceed 100%, repeated for three different shift types:

a. Shift Type One **(Equation 4.12)**

b. Shift Type Two **(Equation 4.13)**

c. Shift Type Three **(Equation 4.14)**

3) Only one coverage segment from each option can be assigned to only one manufacturing cell, repeated for three different shift types:

a. Shift Type One **(Equation 4.15)**

b. Shift Type Two **(Equation 4.16)**

c. Shift Type Three **(Equation 4.17)**

4) If an option is selected then all demand coverage for this option is manufactured. **(Equation 4.18)**

5) Coverage segment 1 for each option in a family must be assigned before coverage segment 2 for that same option and family can be assigned. **(Equation 4.19)**

Mathematical Model:

Objection Function:

$$Min\ Z = \sum_{l=1}^{r}(ShiftACell_l) + 2 * \sum_{l=1}^{r}(ShiftBCell_l) + 3 * \sum_{l=1}^{r}(ShiftCCell_l)$$

Constraints:

$$\boldsymbol{\sum_{j=1}^{w} Option_{ij} = 1}$$

$$\sum_{k=1}^{Q}\sum_{l=1}^{r} ShiftA_{ijkl} = Option_{ij} * A$$

$$\sum_{k=1}^{Q}\sum_{l=2}^{r} \boldsymbol{ShiftB_{ijkl} = Option_{ij} * A}$$

$$\sum_{k=1}^{Q}\sum_{l=3}^{r} \boldsymbol{ShiftC_{ijkl} = Option_{ij} * A}$$

$$\sum_{i=1}^{p}\sum_{j=1}^{w}\sum_{k=1}^{q} \boldsymbol{ExpUtilA_{ijk} * ShiftA_{ijkl} \leq ShiftACell_{l}}$$

$$\sum_{i=1}^{p}\sum_{j=1}^{w}\sum_{k=1}^{q} \boldsymbol{ExpUtilB_{ijk} * ShiftB_{ijkl} \leq ShiftBCell_{l}}$$

$$\sum_{i=1}^{p}\sum_{j=1}^{w}\sum_{k=1}^{q} \boldsymbol{ExpUtilC_{ijk} * ShiftC_{ijkl} \leq ShiftCCell_{l}}$$

$$\sum_{l=1}^{r} \boldsymbol{ShiftA_{ijkl} \leq 1}$$

$$\sum_{l=1}^{r} \boldsymbol{ShiftB_{ijkl} \leq 1}$$

$$\sum_{l=1}^{r} \boldsymbol{ShiftC_{ijkl} \leq 1}$$

$$\sum_{j=1}^{w}\sum_{k=1}^{q}\sum_{l=1}^{r} \boldsymbol{(DemCovA_{ijk} * ShiftA_{ijkl} + DemCovB_{ijk} * ShiftB_{ijkl} + DemCovC_{ijk} * ShiftC_{ijkl}) \geq D}$$

$$\sum_{l=1}^{p} \boldsymbol{ShiftA_{ij(kk-1)l} + ShiftB_{ij(kk-1)l} + ShiftC_{ij(kk-1)l} \geq ShiftA_{ij(kk)l} + ShiftB_{ij(kk)l} + ShiftC_{ij(kk)l}}$$

<u>ILOG-CPLEX OPL Program code explanation</u>

The IBM ILOG-CPLEX (OPL) code and data file is shown in the appendix.

Math Model Results

The results of the OPL mathematical model are shown in Tables 4.46-4.53. The results are shown for the China manufacturing facility + 50% floating demand. This facility will operate using 7 manufacturing cells, operating under the machining time of either shift type 1 (8 hours/day) or shift type 2 (16 hours/day). The results show that family type 2, coverage segment 1 and family type 3, coverage segment 1 will operate under a single shift; all of the other coverage segments for all family types will operate under two shifts. The maximum utilization for a manufacturing cell is 100% for both shift types. This study emphasizes that 100% of demand coverage probability is allocated to the manufacturing facility. Manufacturing cell 1will consist of four different product families so this manufacturing cell is determined as a remainder manufacturing cell. Manufacturing cell 2 will consist of two different product families so this manufacturing cell is determined as shared manufacturing cell. Manufacturing cells 3-7 consist of only one product family so these are determined as a dedicated manufacturing cells. Tables 4.48-4.49, refer to the manufacturing cell allocations, utilization for all manufacturing cells, the number of machine and operator for all manufacturing cells and the total number of machine and operators that the manufacturing system will need to operate under the desired conditions.

Table 4.46 Manufacturing Cell Allocation

China Manufacturing Facility + 50% Floating: Manufacturing Cell Allocation						
16 hours; 2 Shifts: Manufacturing Cells					8 hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
F1O2CS1	F4O12CS4	F4O12CS3	F4O12CS2	F4O12CS1	F2O3CS1	F3O3CS1
F2O3CS2	F5O3CS1					
C3O3CS2						
F4O12CS5						

Table 4.47 Expected Manufacturing Cell Utilization

China Manufacturing Facility + 50% Floating: Utilization Totals						
16 hours; 2 Shifts: Manufacturing Cells					8 hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
18.4%	30.8%	80.3%	98.3%	100.0%	99.5%	99.1%
42.4%	40.6%					
34.9%						
3.0%						
98.7%	71.4%	80.3%	98.3%	100.0%	99.5%	99.1%

Table 4.48 Number of Machines

China Manufacturing Facility + 50% Floating: Number of Machines						
16 hours; 2 Shifts: Manufacturing Cells					8 hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
11	17	17	17	17	11	11
11	17					
11						
17						
17	17	17	17	17	11	11
Total Number of Machines: 107						

Table 4.49 Number of Operators

China Manufacturing Facility +50%: Number of Operators						
16 Hours; 2 Shifts: Manufacturing Cells					8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
17	17	17	17	17	17	23
17	23					
23						
17						
58	46	34	34	34	17	23
Total Operators: 246						

Tables 4.50-4.53 are the mathematical models results for Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility + 50% floating demand.

Table 4.50 Number of Machines

Puerto Rico Manufacturing Facility + 50% Floating: Number of Machines				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
F1O2CS1	F2O3CS1	F3O4CS1	F2O3CS2	F4O8CS1
F4O8CS3	F3O3CS2	F4O8CS4	F4O8CS2	
	F4O8CS5			
	F5O2CS1			

Table 4.51 Utilization Totals

Puerto Rico Manufacturing Facility + 50% Floating: Utilization Totals				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 4	Cell 9	Cell 5	Cell 8	Cell 7
12.6%	62.8%	57.9%	0.1%	100.0%
87.1%	0.002%	27.5%	99.7%	
	0.9%			
	27.8%			
99.7%	91.5%	85.3%	99.7%	100.0%

Table 4.52 Number of Machines

Puerto Rico Manufacturing Facility + 50% Floating: Number of Machines				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
11	11	11	11	17
17	11	17	17	
	17			
	17			
17	17	17	17	17
Total Machines: 85				

Table 4.53 Number of Operators

Puerto Rico Manufacturing Facility + 50% Floating: Number of Operators				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
17	17	23	17	17
17	23	17	17	
	17			
	23			
34	58	58	17	17
Total Machines: 184				

Tables 4.54-4.57 are the mathematical models results for the Limited 2010 Business Strategy Puerto Rico Manufacturing Facility.

Table 4.54 Manufacturing Cell Allocation

Standard Puerto Rico Manufacturing Facility: Manufacturing Cell Allocation							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
F2O8CS1	F3O8CS2	F4O15CS3	F1O2CS1	F4O15CS2	F2O8CS2	F4O15CS1	F3O8CS1
F3O8CS3	F4O15CS6		F4O15CS4		F4O15CS5		
F4O15CS7					F5O3CS1		

Table 4.55 Manufacturing Cell Utilization

Standard Puerto Rico Manufacturing Facility: Manufacturing Cell Utilization							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
92.8%	77.1%	97.1%	21.6%	99.9%	15.2%	100.0%	100.0%
5.3%	7.3%		78.0%		36.7%		
0.5%					47.7%		
98.6%	84.4%	97.1%	99.6%	99.9%	99.5%	100.0%	100.0%

Table 4.56 Number of Machines

Standard Puerto Rico Manufacturing Facility: Number of Machines							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
11	11	17	11	17	11	17	11
11	17		17		17		
17					17		
17	17	17	17	17	17	17	11
Total Machines: 130							

Table 4.57 Number of Operators

Standard Puerto Rico Manufacturing Facility: Number of Operators							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
17	23	17	17	17	17	17	23
23	17		17		17		
17					23		
58	58	34	34	34	58	17	23
Total Operators: 316							

4.6 Total Cost based on Heuristic Algorithm and Mathematical Model

Tables 4.58-4.61 below show the number of machines, machine cost/hr, total machine cost/hr, and the total machine cost/yr for each family type. Since the cost of machine life and tool life are not factored into machine cost, these costs are the same for each shift type.

Table 4.58 Number of Machines for Each Manufacturing Cell

Manufacturing System Number of Machines											
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	5	1	1	1	NA	NA	1	1	NA	11
2	1	5	1	1	1	NA	NA	1	1	NA	11
3	1	5	1	1	1	NA	NA	1	1	NA	11
4	1	5	1	1	1	6	NA	1	1	NA	17
5	1	5	1	1	1	6	NA	1	1	NA	17

Table 4.58 refers to the number of machines that are required for each family type. Table 4.59 refers to the cost for each machine in each product family. In this study, the number of machines in a manufacturing cell is multiple by the cost for each machine

number to create a cost for each family type. These calculations are referred to in Tables 4.60 and 4.61.

Table 4.59 Machine Cost/Hr for Each Manufacturing Cell

Manufacturing System: Machine Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 50.00	$ 30.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 185.00
2	$ 50.00	$ 30.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 185.00
3	$ 50.00	$ 30.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 185.00
4	$ 50.00	$ 30.00	$ 25.00	$ 15.00	$ 20.00	$ 40.00	NA	$ 25.00	$ 20.00	NA	$ 225.00
5	$ 50.00	$ 30.00	$ 25.00	$ 15.00	$ 20.00	$ 40.00	NA	$ 25.00	$ 20.00	NA	$ 225.00

Table 4.60 Total Machine Cost/Hr for Each Manufacturing Cell

Manufacturing System: Total Machine Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 50.00	$ 150.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 305.00
2	$ 50.00	$ 150.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 305.00
3	$ 50.00	$ 150.00	$ 25.00	$ 15.00	$ 20.00	NA	NA	$ 25.00	$ 20.00	NA	$ 305.00
4	$ 50.00	$ 150.00	$ 25.00	$ 15.00	$ 20.00	$ 240.00	NA	$ 25.00	$ 20.00	NA	$ 545.00
5	$ 50.00	$ 150.00	$ 25.00	$ 15.00	$ 20.00	$ 240.00	NA	$ 25.00	$ 20.00	NA	$ 545.00

Table 4.61 Machine Cost/Yr

Manufacturing System: Total Machine Cost/yr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 100,000	$ 300,000	$ 50,000	$ 30,000	$ 40,000	NA	NA	$ 50,000	$ 40,000	NA	$ 610,000
2	$ 100,000	$ 300,000	$ 50,000	$ 30,000	$ 40,000	NA	NA	$ 50,000	$ 40,000	NA	$ 610,000
3	$ 100,000	$ 300,000	$ 50,000	$ 30,000	$ 40,000	NA	NA	$ 50,000	$ 40,000	NA	$ 610,000
4	$ 100,000	$ 300,000	$ 50,000	$ 30,000	$ 40,000	$ 480,000	NA	$ 50,000	$ 40,000	NA	$ 1,090,000
5	$ 100,000	$ 300,000	$ 50,000	$ 30,000	$ 40,000	$ 480,000	NA	$ 50,000	$ 40,000	NA	$ 1,090,000

Table 4.62 refers to the number of operators that are required for each family type. Family types 1, 2 and 4 operate with 17 operators per shift whereas family types 3 and 5 operate with 23 operators per shift. These figures are the number of required operators for both the manufacturing and packaging operations.

Table 4.62 Number of Operators for each Manufacturing Cell

Manufacturing System Number of Operators											
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	1	5	1	1	1	NA	6	1	1	NA	17
2	1	5	1	1	1	NA	6	1	1	NA	17
3	1	5	1	1	1	NA	6	1	1	6	23
4	1	5	1	1	1	6	NA	1	1	NA	17
5	1	5	1	1	1	6	NA	1	1	6	23

Tables 4.63-4.67 refer to the cost for the China manufacturing facility in terms of operation costs. Cost for operators is the same for each operator in each product family. According to Ates (2013) average industry wage for a worker in China is $1.95 /hr.

Table 4.63 China Operator Cost

China Manufacturing System: Operator Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	NA	$ 1.95	$ 1.95	$ 1.95	NA	$ 15.60
2	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	NA	$ 1.95	$ 1.95	$ 1.95	NA	$ 15.60
3	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	NA	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 17.55
4	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	NA	$ 1.95	$ 1.95	NA	$ 15.60
5	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	$ 1.95	NA	$ 1.95	$ 1.95	$ 1.95	$ 17.55

Table 4.64 China Total Operator Cost

China Manufacturing System: Total Operator Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 1.95	$ 9.75	$ 1.95	$ 1.95	$ 1.95	NA	$ 11.70	$ 1.95	$ 1.95	NA	$ 33.15
2	$ 1.95	$ 9.75	$ 1.95	$ 1.95	$ 1.95	NA	$ 11.70	$ 1.95	$ 1.95	NA	$ 33.15
3	$ 1.95	$ 9.75	$ 1.95	$ 1.95	$ 1.95	NA	$ 11.70	$ 1.95	$ 1.95	$ 11.70	$ 44.85
4	$ 1.95	$ 9.75	$ 1.95	$ 1.95	$ 1.95	$ 11.70	NA	$ 1.95	$ 1.95	NA	$ 33.15
5	$ 1.95	$ 9.75	$ 1.95	$ 1.95	$ 1.95	$ 11.70	NA	$ 1.95	$ 1.95	$ 11.70	$ 44.85

Table 4.65 China Total Operator Cost: 2000 Hours

China Manufacturing System: Total Operator Cost/yr for Shift Type 1 (2000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 3,900	$ 19,500	$ 3,900	$ 3,900	$ 3,900	NA	$ 23,400	$ 3,900	$ 3,900	NA	$ 66,300
2	$ 3,900	$ 19,500	$ 3,900	$ 3,900	$ 3,900	NA	$ 23,400	$ 3,900	$ 3,900	NA	$ 66,300
3	$ 3,900	$ 19,500	$ 3,900	$ 3,900	$ 3,900	NA	$ 23,400	$ 3,900	$ 3,900	$ 23,400	$ 89,700
4	$ 3,900	$ 19,500	$ 3,900	$ 3,900	$ 3,900	$ 23,400	NA	$ 3,900	$ 3,900	NA	$ 66,300
5	$ 3,900	$ 19,500	$ 3,900	$ 3,900	$ 3,900	$ 23,400	NA	$ 3,900	$ 3,900	$ 23,400	$ 89,700

Table 4.66 China Total Operator Cost: 4000 Hours

China Manufacturing System: Total Operator Cost/yr for Shift Type 2 (4000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 7,800	$ 39,000	$ 7,800	$ 7,800	$ 7,800	NA	$ 46,800	$ 7,800	$ 7,800	NA	$ 132,600
2	$ 7,800	$ 39,000	$ 7,800	$ 7,800	$ 7,800	NA	$ 46,800	$ 7,800	$ 7,800	NA	$ 132,600
3	$ 7,800	$ 39,000	$ 7,800	$ 7,800	$ 7,800	NA	$ 46,800	$ 7,800	$ 7,800	$ 46,800	$ 179,400
4	$ 7,800	$ 39,000	$ 7,800	$ 7,800	$ 7,800	$ 46,800	NA	$ 7,800	$ 7,800	NA	$ 132,600
5	$ 7,800	$ 39,000	$ 7,800	$ 7,800	$ 7,800	$ 46,800	NA	$ 7,800	$ 7,800	$ 46,800	$ 179,400

Table 4.67 China Operator Cost: 6000 Hours

China Manufacturing System: Total Operator Cost/yr for Shift Type 3 (6000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 11,700	$ 58,500	$ 11,700	$ 11,700	$ 11,700	NA	$ 70,200	$ 11,700	$ 11,700	NA	$ 198,900
2	$ 11,700	$ 58,500	$ 11,700	$ 11,700	$ 11,700	NA	$ 70,200	$ 11,700	$ 11,700	NA	$ 198,900
3	$ 11,700	$ 58,500	$ 11,700	$ 11,700	$ 11,700	NA	$ 70,200	$ 11,700	$ 11,700	$ 70,200	$ 269,100
4	$ 11,700	$ 58,500	$ 11,700	$ 11,700	$ 11,700	$ 70,200	NA	$ 11,700	$ 11,700	NA	$ 198,900
5	$ 11,700	$ 58,500	$ 11,700	$ 11,700	$ 11,700	$ 70,200	NA	$ 11,700	$ 11,700	$ 70,200	$ 269,100

Tables 4.68-4.72 refer to the cost for the Puerto Rico manufacturing facility in terms of operation costs. Cost for operators is the same for each operator in each product family. According to Ates (2013) average industry wage for a worker in North America is $21.49 /hr.

Table 4.68 North America Wage Cost

Puerto Rico Manufacturing System: Total Operator Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	NA	$ 21.49	$ 21.49	$ 21.49	NA	$ 171.92
2	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	NA	$ 21.49	$ 21.49	$ 21.49	NA	$ 171.92
3	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	NA	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 193.41
4	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	NA	$ 21.49	$ 21.49	NA	$ 171.92
5	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	$ 21.49	NA	$ 21.49	$ 21.49	$ 21.49	$ 193.41

Table 4.69 Total Operator Cost/Hr

Puerto RicoManufacturing System: Total Operator Cost/hr											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 21.49	$ 107.45	$ 21.49	$ 21.49	$ 21.49	NA	$ 128.94	$ 21.49	$ 21.49	NA	$ 365.33
2	$ 21.49	$ 107.45	$ 21.49	$ 21.49	$ 21.49	NA	$ 128.94	$ 21.49	$ 21.49	NA	$ 365.33
3	$ 21.49	$ 107.45	$ 21.49	$ 21.49	$ 21.49	NA	$ 128.94	$ 21.49	$ 21.49	$ 128.94	$ 494.27
4	$ 21.49	$ 107.45	$ 21.49	$ 21.49	$ 21.49	$ 128.94	NA	$ 21.49	$ 21.49	NA	$ 365.33
5	$ 21.49	$ 107.45	$ 21.49	$ 21.49	$ 21.49	$ 128.94	NA	$ 21.49	$ 21.49	$ 128.94	$ 494.27

Table 4.70 Puerto Rico Operator Cost: 2000 Hours

Puerto Rico Manufacturing System: Total Operator Cost/yr for Shift Type 1 (2000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 42,980	$ 214,900	$ 42,980	$ 42,980	$ 42,980	NA	$ 257,880	$ 42,980	$ 42,980	NA	$ 730,660
2	$ 42,980	$ 214,900	$ 42,980	$ 42,980	$ 42,980	NA	$ 257,880	$ 42,980	$ 42,980	NA	$ 730,660
3	$ 42,980	$ 214,900	$ 42,980	$ 42,980	$ 42,980	NA	$ 257,880	$ 42,980	$ 42,980	$ 257,880	$ 988,540
4	$ 42,980	$ 214,900	$ 42,980	$ 42,980	$ 42,980	$ 257,880	NA	$ 42,980	$ 42,980	NA	$ 730,660
5	$ 42,980	$ 214,900	$ 42,980	$ 42,980	$ 42,980	$ 257,880	NA	$ 42,980	$ 42,980	$ 257,880	$ 988,540

Table 4.71 Puerto Rico Operator Cost: 4000 Hours

Puerto Rico Manufacturing System: Total Operator Cost/yr for Shift Type 2 (4000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 85,960	$ 429,800	$ 85,960	$ 85,960	$ 85,960	NA	$ 515,760	$ 85,960	$ 85,960	NA	$ 1,461,320
2	$ 85,960	$ 429,800	$ 85,960	$ 85,960	$ 85,960	NA	$ 515,760	$ 85,960	$ 85,960	NA	$ 1,461,320
3	$ 85,960	$ 429,800	$ 85,960	$ 85,960	$ 85,960	NA	$ 515,760	$ 85,960	$ 85,960	$ 515,760	$ 1,977,080
4	$ 85,960	$ 429,800	$ 85,960	$ 85,960	$ 85,960	$ 515,760	NA	$ 85,960	$ 85,960	NA	$ 1,461,320
5	$ 85,960	$ 429,800	$ 85,960	$ 85,960	$ 85,960	$ 515,760	NA	$ 85,960	$ 85,960	$ 515,760	$ 1,977,080

Table 4.72 Puerto Rico Operator Cost: 6000 Hours

Puerto Rico Manufacturing System: Total Operator Cost/yr for Shift Type 3 (6000 hours)											
FamilyType	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6auto	Opr6man	Opr7	Opr8	Opr9	Total
1	$ 128,940	$ 644,700	$ 128,940	$ 128,940	$ 128,940	NA	$ 773,640	$ 128,940	$ 128,940	NA	$ 2,191,980
2	$ 128,940	$ 644,700	$ 128,940	$ 128,940	$ 128,940	NA	$ 773,640	$ 128,940	$ 128,940	NA	$ 2,191,980
3	$ 128,940	$ 644,700	$ 128,940	$ 128,940	$ 128,940	NA	$ 773,640	$ 128,940	$ 128,940	$ 773,640	$ 2,965,620
4	$ 128,940	$ 644,700	$ 128,940	$ 128,940	$ 128,940	$ 773,640	NA	$ 128,940	$ 128,940	NA	$ 2,191,980
5	$ 128,940	$ 644,700	$ 128,940	$ 128,940	$ 128,940	$ 773,640	NA	$ 128,940	$ 128,940	$ 773,640	$ 2,965,620

4.7 Total Manufacturing System Cost Based on Heuristic Algorithm and Mathematical Model (OPL)

The heuristic algorithm produced results for the manufacturing system for a total of seven manufacturing cells with five operating at shift type 2 and two manufacturing cells operating at shift type 1. The results are based on calculations from tables above and total manufacturing system calculations are shown in the tables below for the China manufacturing facility with the addition of 50% of the floating demand.

Table 4.73 Operator Cost/Year

Heuristic Algorithm China Manufacturing Facility Operator Cost/yr						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 132,600	$ 132,600	$ 132,600	$ 132,600	$ 132,600	$ 89,700	$ 89,700
			$ 132,600	$ 132,600		
			$ 179,400			
			$ 179,400			
			$ 132,600			
$ 132,600	$ 132,600	$ 132,600	$ 179,400	$ 132,600	$ 89,700	$ 89,700
Total Cost: $889,200						

Table 4.74 Machine Cost/Year

Heuristic Algorithm China Manufacturing Facility Machine Cost/yr						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 610,000	$ 1,090,000
			$ 610,000	$ 610,000		
			$ 610,000			
			$ 1,090,000			
			$ 610,000			
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 610,000	$ 1,090,000
Total Cost: $7,150,000						

Table 4.75 Total Manufacturing Cost/Year

Heuristic Algorithm China Manufacturing Facility Total Manufacturing Cost/yr						
16 hours; 2 Shifts Manufacturing Cells					8 hours; 1 Shift	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 1,222,600	$ 1,222,600	$ 1,222,600	$ 1,222,600	$ 1,222,600	$ 699,700	$ 1,179,700
			$ 742,600	$ 742,600		
			$ 789,400			
			$ 1,269,400			
			$ 742,600			
$ 1,222,600	$ 1,222,600	$ 1,222,600	$ 1,269,400	$ 1,222,600	$ 699,700	$ 1,179,700
Total Cost: $8,039,200						

The mathematical model produced results for the manufacturing system for a total of seven manufacturing cells with five operating at shift type 2 and two manufacturing cells operating at shift type 1. The results are based on calculations from tables above and total manufacturing system calculations are shown in the tables below for the Expanded 2011 Business Strategy China manufacturing facility with the addition of 50% of the floating demand.

Table 4.76 Expanded 2011 China Facility Machine Cost

Expanded 2011 China Manufacturing Facility + 50% Floating: Machine Cost						
16 Hours; 2 Shifts: Manufacturing Cells					8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 610,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 610,000.00	$ 610,000.00
$ 610,000.00	$ 1,090,000.00					
$ 610,000.00						
$ 1,090,000.00						
$ 1,090,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 1,090,000.00	$ 610,000.00	$ 610,000.00
Total Machine Cost: $6,670,000						

Table 4.77 Expanded 2011 China Facility Operator Cost

Expanded 2011 China Manufacturing Facility + 50% Floating: Operators Cost						
16 Hours; 2 Shifts: Manufacturing Cells					8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 132,600.00	$ 132,600.00	$ 132,600.00	$ 132,600.00	$ 132,600.00	$ 66,300.00	$ 89,700.00
$ 132,600.00	$ 179,400.00					
$ 179,400.00						
$ 132,600.00						
$ 249,600.00	$ 249,600.00	$ 132,600.00	$ 132,600.00	$ 132,600.00	$ 66,300.00	$ 89,700.00
Total Operator Cost: $1,053,000						

Table 4.78 Expanded 2011 China Facility Total Manufacturing System Cost

Expanded 2011 China Manufacturing Facility + 50% Floating: Total Manufacturing System Cost						
16 Hours; 2 Shifts: Manufacturing Cells					8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 742,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 676,300.00	$ 699,700.00
$ 742,600.00	$ 1,269,400.00					
$ 789,400.00						
$ 1,222,600.00						
$ 1,339,600.00	$ 1,339,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 676,300.00	$ 699,700.00
Total System Cost: $7,723,000						

Comparing the two approaches; the heuristic algorithm and the OPL model, both models operate with seven manufacturing cells. The OPL model was able to manufacturing the desired quantities for a cheaper price than the heuristic algorithm. This was achieved from the different combination of family types and coverage segments. Tables 4.79-7.81 refer to the Heuristic Algorithm machine cost, operator cost, and manufacturing system cost for Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility + 50% Floating Demand.

Table 4.79 Expanded 2011 Puerto Rico Total Machine Cost

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Heuristic Algorithm Total Machine Cost			
Cell 1	Cell 2	Cell 3	Cell 4
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000
		$ 610,000	$ 610,000
		$ 610,000	$ 610,000
		$ 610,000	$ 1,090,000
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000
Total Machine Cost: $4,360,000			

Table 4.80 Expanded 2011 Puerto Rico Total Operator Cost

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Heuristic Algorithm Total Operator Cost			
Cell 1	Cell 2	Cell 3	Cell 4
$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 1,461,320
		$ 1,461,320	$ 1,461,320
		$ 1,977,080.00	$ 1,977,080.00
		$ 1,461,320	$ 1,977,080.00
$ 1,461,320	$ 1,461,320	$ 2,492,840	$ 2,492,840
Total Operator Cost: $7,908,320			

Table 4.81 Expanded 2011 Puerto Rico Total System Cost

Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility + 50% Floating Demand: Heuristic Algorithm Total Manufacturing System Cost			
Cell 1	Cell 2	Cell 3	Cell 4
$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 2,551,320
		$ 2,071,320	$ 2,071,320
		$ 2,587,080	$ 2,587,080
		$ 2,071,320	$ 3,067,080
$ 2,551,320	$ 2,551,320	$ 3,582,840	$ 3,582,840
Total Operator Cost: $12,268,320			

Tables 4.82-4.84 refer to the Mathematical Modeling (OPL) machine cost, operator cost, and manufacturing system cost for Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility + 50% Floating Demand.

Table 4.82 Expanded 2011 Puerto Rico Machine Cost

Puerto Rico Manufacturing Facility + 50% Floating: Machine Cost				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
$ 610,000	$ 610,000	$ 610,000	$ 610,000	$ 1,090,000
$ 1,090,000	$ 610,000	$ 1,090,000	$ 1,090,000	
	$ 1,090,000			
	$ 1,090,000			
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000
Total Machines Cost: $5,450,000				

Table 4.83 Expanded 2011 Puerto Rico Operator Cost

Puerto Rico Manufacturing Facility + 50% Floating: Operator Cost				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
$ 1,461,320	$ 1,461,320	$ 1,977,080	$ 730,660	$ 730,660
$ 1,461,320	$ 1,977,080	$ 1,461,320	$ 730,660	
	$ 1,461,320			
	$ 1,977,080			
$ 1,461,320	$ 2,492,840	$ 1,977,080	$ 730,660	$ 730,660
Total Operator Cost: $7,392,560				

Table 4.84 Expanded 2011 Puerto Rico Total Manufacturing System Cost

Puerto Rico Manufacturing Facility + 50% Floating: Total Manufacturing System				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
$ 2,071,320	$ 2,071,320	$ 2,587,080	$ 1,340,660	$ 1,820,660
$ 2,551,320	$ 2,587,080	$ 2,551,320	$ 1,820,660	
	$ 2,551,320			
	$ 3,067,080			
$ 2,551,320	$ 4,062,840	$ 2,587,080	$ 1,820,660	$ 1,820,660
Total System Cost: $12,842,560				

Table 4.85 refers to the manufacturing system cost for the Expanded 2011 Business Strategy based on the mathematical model results.

Table 4.85 Expanded 2011 Business Strategy Total Manufacturing System Cost

Combined China & Puerto Rico Manufacturing Facilities + 50% Floating: Total Manufacturing System Cost	
16 Hours; 2 Shifts: Manufacturing Cells	8 Hours; 1 Shift: Manufacturing Cells
All Cells	All Cells
$ 15,548,240.00	$ 5,017,320.00
Total System Cost: $20,565,560	

Tables 4.86-4.88 refer to the Heuristic Algorithm machine cost, operator cost, and manufacturing system cost for Limited 2010 Business Strategy Puerto Rico Manufacturing Facility.

Table 4.86 Limited 2010 Puerto Rico Total Machine Cost

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Heuristic Algorithm Total Machine Cost								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 610,000	$ 610,000	$ 1,090,000
			$ 610,000	$ 610,000	$ 610,000			
			$ 1,090,000	$ 610,000				
			$ 610,000					
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 610,000	$ 610,000	$ 1,090,000
Total Machine Cost: $8,850,000								

Table 4.87 Limited 2010 Puerto Rico Total Operator Cost

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Heuristic Algorithm Total Operators Cost								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 730,660	$ 730,660	$ 988,540.00
			$ 1,977,080.00	$ 1,977,080.00	$ 1,977,080.00			
			$ 1,977,080.00	$ 1,461,320				
			$ 1,461,320					
$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 2,492,840	$ 2,492,840	$ 2,492,840	$ 730,660	$ 730,660	$ 988,540
Total Operators Cost: $14,312,340								

Table 4.88 Limited 2010 Puerto Rico Total System Cost

Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility: Heuristic Algorithm Total System Cost								
16 Hours: 2 shift Manufacturing Cells						8 Hours: 1 shift Manufacturing Cells		
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9
$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 1,340,660	$ 1,340,660	$ 2,078,540
			$ 2,587,080	$ 2,587,080	$ 2,587,080			
			$ 3,067,080	$ 2,071,320				
			$ 2,071,320					
$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 3,582,840	$ 3,582,840	$ 3,582,840	$ 1,340,660	$ 1,340,660	$ 2,078,540
Total Operators Cost: $23,162,340								

Tables 4.89-4.91 refer to the Mathematical Modeling (OPL) machine cost, operator cost, and manufacturing system cost for Limited 2010 Business Strategy Puerto Rico Manufacturing Facility.

Table 4.89 Limited 2010 Puerto Rico Machine Cost

Limited 2010 Puerto Rico Manufacturing Facility: Machine Cost							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
$ 610,000	$ 610,000	$ 1,090,000	$ 610,000	$ 1,090,000	$ 610,000	$ 1,090,000	$ 610,000
$ 610,000	$ 1,090,000		$ 1,090,000		$ 1,090,000		
$ 1,090,000					$ 1,090,000		
$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 1,090,000	$ 610,000
Total Machine Cost: $8,240,000							

Table 4.90 Limited 2010 Puerto Rico Operator Cost

Limited 2010 Puerto Rico Manufacturing Facility: Operator Cost							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
$ 1,461,320	$ 1,977,080	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 730,660	$ 988,540
$ 1,977,080	$ 1,461,320		$ 1,461,320		$ 1,461,320		
$ 1,461,320					$ 1,977,080		
$ 2,492,840	$ 2,492,840	$ 1,461,320	$ 1,461,320	$ 1,461,320	$ 2,492,840	$ 730,660	$ 988,540
Total Operator Cost: $13,581,680							

Table 4.91 Limited 2010 Puerto Rico Total Manufacturing Cost

Limited 2010 Puerto Rico Manufacturing Facility: Total Manufacturing System Cost							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
$ 2,071,320	$ 2,587,080	$ 2,551,320	$ 2,071,320	$ 2,551,320	$ 2,071,320	$ 1,820,660	$ 1,598,540
$ 2,587,080	$ 2,551,320		$ 2,551,320		$ 2,551,320		
$ 2,551,320					$ 3,067,080		
$ 3,582,840	$ 3,582,840	$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 3,582,840	$ 1,820,660	$ 1,598,540
Total System Cost: $21,821,680							

Tables 4.92 and 4.93 refer to the manufacturing system cost between Limited 2010 Business Strategy and Expanded 2011 Business Strategy. For future comparison, this study uses the Mathematical Modeling (OPL) results to compare the two business strategies. The Expanded 2011 Business Strategy manufacturing system cost less than the

2010 Business Strategy and will also product more vials. This is due to the lower cost for operators in China compared to Puerto Rico.

Table 4.92 Comparison between Heuristic Algorithm and Mathematical Modeling

Comparison between Heurisitic Algorithm and Mathematical Modeling (OPL)						
	Heurisitc Algorithm			Mathematical Modeling (OPL)		
	Expanded 2011		Limited 2010	Expanded 2011		Limited 2010
	China	Puerto Rico	Puerto Rico	China	Puerto Rico	Puerto Rico
Machines	113	68	141	107	85	130
Operator	240	184	333	258	184	316
System Cost	$ 8,039,200.00	$ 12,268,320.00	$ 23,162,340.00	$ 7,723,000.00	$ 12,842,560.00	$ 21,821,680.00
Total System Cost	$20,307,520.00		$ 23,162,340.00	$20,565,560.00		$ 21,821,680.00

Table 4.93 Comparison of Limited 2010 and Expanded 2011 Business Strategies

Cost Comparison Between Limited 2010 Business Strategy and Expanded 2011 Business Strategy: Total Manufacturing System Cost	
16 Hours; 2 Shifts: Manufacturing Cells	8 Hours; 1 Shift: Manufacturing Cells
All Cells	All Cells
$ (2,854,240.00)	$ 1,598,120.00
2011 Total Manufacturing System Cost Difference: ($1,256,120)	

Once the manufacturing system calculations are completed, this study then designs a simulation model using Arena Simulation software to better understand the manufacturing process. The simulation is described in Chapter 5.

5 Simulation

Mathematical modeling minimized the number of manufacturing cells, while the heuristic algorithm grouped product families based on similar characteristics to find near optimal solutions. The results to the mathematical model need to be tested to see if the manufacturing system can indeed meet these standards. To solve this, the manufacturing system design is implemented into an Arena simulation model. The simulation model inputs are based on outputs from the mathematical model and the heuristic algorithm. This study uses the outputs from the mathematical model.

5.1 Arena Simulation Software

This study uses an Arena simulation software program that was developed by Rockwell Software Inc. Arena is a discrete simulation based on flow oriented simulation language called SIMAN. The software is compatible with Microsoft Excel so data can easily be imported from excel into Arena with VBA coding. Arena simulation models are designed by the user using a technique called model building. Model building is constructing a set of events based on preexisting blocks or nodes. Arena has these nodes already created so a node can easily be dragged from the project bar to the model window. The simulation is built from a set of nodes that are combined together to form a flow path.

5.1.1 VBA Coding

This study uses VBA coding to connect Microsoft Excel and Arena simulation. VBA coding is a programming technique that is used for Microsoft programs. Connecting the two programs will allow for user inputs to be placed into excel and then read into Arena with a click of a button. This will allow changes to be simulation to be quick and easy for the user.

5.1.2 Vial Demand Allocation

Vial demand allocation is based on different regions from different manufacturing facility. Referring back to Chapter 3, where the Puerto Rico manufacturing facility and the China manufacturing facility manufacture Lifescan products for different parts of the world. This section describes the different vial allocations to different regions and the processing times of the manufacturing system (based on current Lifescan machine technology). Table 5.1, shows the vial demand allocation that will be manufactured in the China manufacturing facility. This data is based on the demand for China manufacturing facility + 50% floating for all five family types. Family 1, has a vial demand of 5,293,776 vials and is 3.35% of the total demand that is allocated to the China manufacturing facility.

Table 5.1 China + 50% Floating Simulation Individual Vial Demand

China Manufacturing Facility + 50% Floating Demand: Individual Vial Demand		
Family Type	Vial Demand	Distribution
1	5,293,776	3.35%
2	26,419,601	16.70%
3	24,308,064	15.37%
4	90,494,452	57.20%
5	11,677,667	7.38%
Total	158,193,560	100.00%

Table 5.2 Puerto Rico + 50% Demand Simulation Individual Vial Demand

2011 Expanded Business Strategy: Puerto Rico + 50% Floating		
Family Type	Vial Demand	Distribution
1	3,628,077	3.35%
2	18,106,609	16.70%
3	16,659,473	15.37%
4	62,020,152	57.20%
5	8,003,261	7.38%
Total	108,417,571	100.00%

Table 5.3 Limited 2010 Puerto Rico Simulation Individual Vial Demand

2010 Standard Business Strategy: Puerto Rico Manufacturing Facility		
Family Type	Vial Demand	Distribution
1	4,149,210	3.35%
2	20,707,427	16.70%
3	19,052,425	15.37%
4	70,928,674	57.20%
5	9,152,842	7.38%
Total	123,990,578	100.00%

5.2 Vial Production Rates (Individual & Batch)

This section describes the manufacturing facility based on the production rate for different machines. Table 5.4, explains that to manufacture family type 1 with operation 1, the system needs to allocate 0.00833 minutes of production time to manufacture this section of the vial. Remember from Chapter 4, that a total of 8 or 9 operations, depending on the family type. For each family type all operations must be done in chorological order so must perform operation 1 before operation 2 and so on. All operations for a family type are considered a family type sequence. Each operation for a family type sequence is allocated a processing time. These processing times are the amount of time that it will take an operation to manufacture its portion of the vial. As stated before, family types 1, 2 and 4 have 8 operations in the family type sequence whereas family types 3 and 5 have 9 operations in the family type sequence. In family type 1, operation 1 processing time for this operation is 0.00883 minutes to finish one vial. The highest processing time for an operation amount for each family type sequence is considered the bottleneck operation. Each family type sequence may have one or multiple bottleneck operations.

Table 5.4 Expanded 2011 Manufacturing System Production Rates

China Manufacturing Facility + 50% Floating Demand: Single Vial Production Rates for Machines (min)										
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9	Bottleneck
1	0.00833	0.00702	0.00813	0.00625	0.00741	0.00833	NA	0.00667	0.00667	NA	0.00833
2	0.00833	0.00702	0.00813	0.00625	0.00741	0.00833	NA	0.00667	0.00667	NA	0.00833
3	0.00833	0.00702	0.00813	0.00625	0.00741	0.00833	NA	0.00667	0.00667	0.00833	0.00833
4	0.00833	0.00702	0.00813	0.00625	0.00741	NA	0.00833	0.00667	0.00667	NA	0.00833
5	0.00833	0.00702	0.00813	0.00625	0.00741	NA	0.00833	0.00667	0.00667	0.00833	0.00833

Additional machines added to operation 2, operation 6 auto, operation 6 man, and operation 9 for additional manufacturing system output. Table 5.4 is multiplied by the number of machines for each operation based on each family type to form the system production rates as shown in Table 5.5.

Table 5.5 New 2011 Manufacturing System Production Rates on Total Machines

China Manufacturing Facility + 50% Floating Demand: Single Vial Production Rates for Individual Machines (min)										
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9
1	0.00833	0.03509	0.00813	0.00625	0.00741	0.05000	NA	0.00667	0.00667	NA
2	0.00833	0.03509	0.00813	0.00625	0.00741	0.05000	NA	0.00667	0.00667	NA
3	0.00833	0.03509	0.00813	0.00625	0.00741	0.05000	NA	0.00667	0.00667	0.05000
4	0.00833	0.03509	0.00813	0.00625	0.00741	NA	0.05000	0.00667	0.00667	NA
5	0.00833	0.03509	0.00813	0.00625	0.00741	NA	0.05000	0.00667	0.00667	0.05000

Table 5.6 describes the manufacturing system based on the number of vials that are manufactured per minute which is based on operation number and family type. The manufacturing system bottleneck is described as operation 1, operation 6 auto, operation 6 man, and operation 9 with all have a production rate of 120 vials per minute.

Table 5.6 New 2011 Manufacturing System Quantity Production Rates

China Manufacturing Facility + 50% Floating Demand: Individual Vial Quantity Production (vials/min)											
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9	Bottleneck
1	120	143	123	160	135	120	NA	150	150	NA	120
2	120	143	123	160	135	120	NA	150	150	NA	120
3	120	143	123	160	135	120	NA	150	150	120	120
4	120	143	123	160	135	NA	120	150	150	NA	120
5	120	143	123	160	135	NA	120	150	150	120	120

5.2.1 Demand Allocation

Going back to Chapter 3, there is a total of six different regions that a manufacturing plant can allocate demand to. With demand being manufactured in the China manufacturing facility, the region allocations are listed as:

1) China Manufacturing Facility to Africa region
2) China Manufacturing Facility to Asia region
3) China Manufacturing Facility to Europe region
4) China Manufacturing Facility to Latin America region
5) China Manufacturing Facility to North America region
6) China Manufacturing Facility to Oceana region

Table 5.7 Expanded 2011 Individual Vial Demand Allocation

China Manufacturing Facility+ 50% Floating Demand: Individual Vial Demand Allocation							
Family Type	Manufacturing Plant to Region	Vial Percentage	Percent of Total	Quantity	Interarrival Rate (in min) shift of 2000 hours	Interarrival Rate (in min) shift of 4000 hours	Interarrival Rate (in min) shift of 6000 hours
Family 1	China to Africa	3.35%	25.15%	1,331,626	0.09	0.18	0.27
	China to Asia		61.95%	3,279,718	0.04	0.07	0.11
	China to Europe		5.47%	289,806	0.41	0.83	1.24
	China to Latin America		6.35%	336,214	0.36	0.71	1.07
	China to North America		1.03%	54,551	2.20	4.40	6.60
	China to Oceana		0.04%	1,865	64.34	128.69	193.03
Family 2	China to Africa	16.70%	25.15%	6,645,731	0.02	0.04	0.05
	China to Asia		61.95%	16,368,057	0.01	0.01	0.02
	China to Europe		5.47%	1,446,329	0.08	0.17	0.25
	China to Latin America		6.35%	1,677,939	0.07	0.14	0.21
	China to North America		1.03%	272,243	0.44	0.88	1.32
	China to Oceana		0.04%	9,305	12.90	25.79	38.69
Family 3	China to Africa	15.37%	25.15%	6,114,584	0.02	0.04	0.06
	China to Asia		61.95%	15,059,871	0.01	0.02	0.02
	China to Europe		5.47%	1,330,734	0.09	0.18	0.27
	China to Latin America		6.35%	1,543,833	0.08	0.16	0.23
	China to North America		1.03%	250,485	0.48	0.96	1.44
	China to Oceana		0.04%	8,561	14.02	28.03	42.05
Family 4	China to Africa	57.20%	25.15%	22,763,469	0.01	0.01	0.02
	China to Asia		61.95%	56,065,127	0.00	0.00	0.01
	China to Europe		5.47%	4,954,078	0.02	0.05	0.07
	China to Latin America		6.35%	5,747,403	0.02	0.04	0.06
	China to North America		1.03%	932,507	0.13	0.26	0.39
	China to Oceana		0.04%	31,871	3.77	7.53	11.30
Family 5	China to Africa	7.38%	25.15%	2,937,465	0.04	0.08	0.12
	China to Asia		61.95%	7,234,807	0.02	0.03	0.05
	China to Europe		5.47%	639,289	0.19	0.38	0.56
	China to Latin America		6.35%	741,662	0.16	0.32	0.49
	China to North America		1.03%	120,334	1.00	1.99	2.99
	China to Oceana		0.04%	4,113	29.18	58.35	87.53

5.2.2 Batch Production

Due to Arena simulation limitation for the amount of products the system can produce we had to reduce the vial demand figures and conclude that vials are produced in batches of 1,000. This resulted in all demand being divided by 1,000 and all processing times being multiple by 1,000 to produce the batches of 1,000. The changes are shown in Tables 5.8-5.10. Table 5.8 may look like a bottleneck, based on individual machines is operation 6 auto but when all machines are allocated to manufacturing vials and if the manufacture was ran for over 50 minutes then operation 6 auto production would perform the same as operation 1 so both are considered bottleneck operations. Table 5.9 describes the output per minute of production and is in terms of fractional batch sizes, but since a batch is in terms of 1,000 this is feasible.

Table 5.8 Expanded 2011 China Batch Vial Demand

China Manufacturing Facility + 50% Floating Demand: Batch Vial Demand		
Family Type	Vial Demand	Distribution
1	5,294	3.35%
2	26,420	16.70%
3	24,308	15.37%
4	90,494	57.20%
5	11,678	7.38%
Total	158,194	100.00%

Table 5.9 Expanded 2011 Puerto Rico Batch Vial Demand

2011 Expanded Business Strategy: Puerto Rico + 50% Floating Batch Vial Demand		
Family Type	Vial Demand	Distribution
1	3,628	3.35%
2	18,107	16.70%
3	16,659	15.37%
4	62,020	57.20%
5	8,003	7.38%
Total	108,418	100.00%

Table 5.10 Expanded 2011 Puerto Rico Batch Vial Demand

2010 Standard Business Strategy: Puerto Rico Manufacturing Facility Batch Vial Demand		
Family Type	Vial Demand	Distribution
1	4,149	3.35%
2	20,707	16.70%
3	19,052	15.37%
4	70,929	57.20%
5	9,153	7.38%
Total	123,991	100.00%

Due to Arean Simulation constants, this study simulates the number of vials in batches of 1,000 vials. Table 5.11 describes the batch processing rate for each operation.

Table 5.11 Expanded 2011 China Batch Processing Rates

China Manufacturing Facility + 50% Floating Demand: Batch Processing Rates for Machines (min)											
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9	Bottleneck
1	8.333	7.018	8.130	6.250	7.407	8.330	NA	6.667	6.667	NA	8.333
2	8.333	7.018	8.130	6.250	7.407	8.330	NA	6.667	6.667	NA	8.333
3	8.333	7.018	8.130	6.250	7.407	8.330	NA	6.667	6.667	8.330	8.333
4	8.333	7.018	8.130	6.250	7.407	NA	8.330	6.667	6.667	NA	8.333
5	8.333	7.018	8.130	6.250	7.407	NA	8.330	6.667	6.667	8.330	8.333

The batch processing times are multiplied by the number of machines, resulting in Table 5.12. These are the processing time for the manufacturing system that are used in the Arena Simulation.

Table 5.12 Expanded 2011 China Batch Processing Rates for System

China Manufacturing Facility + 50% Floating Demand: Batch Processing Rates for Individual Machines (min)										
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9
1	8.333	35.088	8.130	6.250	7.407	50.000	NA	6.667	6.667	NA
2	8.333	35.088	8.130	6.250	7.407	50.000	NA	6.667	6.667	NA
3	8.333	35.088	8.130	6.250	7.407	50.000	NA	6.667	6.667	50.000
4	8.333	35.088	8.130	6.250	7.407	NA	50.000	6.667	6.667	NA
5	8.333	35.088	8.130	6.250	7.407	NA	50.000	6.667	6.667	50.000

Table 5.13 is the number of batches for each operation that is manufactured per minute of operation.

Table 5.13 Expanded 2011 China Batch Quantity Processing Rates for System

China Manufacturing Facility + 50% Floating Demand: Batch Vial Quantity Production (vials batches/min)											
Family Type	Opr1	Opr2	Opr3	Opr4	Opr5	Opr6Auto	Opr6Man	Opr7	Opr8	Opr9	Bottleneck
1	0.12	0.14	0.12	0.16	0.14	0.12	NA	0.15	0.15	NA	0.12
2	0.12	0.14	0.12	0.16	0.14	0.12	NA	0.15	0.15	NA	0.12
3	0.12	0.14	0.12	0.16	0.14	0.12	NA	0.15	0.15	0.12	0.12
4	0.12	0.14	0.12	0.16	0.14	NA	0.12	0.15	0.15	NA	0.12
5	0.12	0.14	0.12	0.16	0.14	NA	0.12	0.15	0.15	0.12	0.12

The batch allocation is the same as the individual allocation except that all quantities are divided by 1,000, thus raising the inter-arrival rates and the processing rates for machines. This process is repeated for different demand allocations of floating demand and also for the 2010 Limited Puerto Rico manufacturing facility.

Table 5.14 Batch Vial Demand Allocation

China Manufacturing Facility + 50% Floating Demand: Batch Vial Demand Allocation							
Family Type	Manufacturing Plant to Region	Vial Percentage	Percent of Total	Quantity	Interarrival Rate (in min) shift of 2000 hours	Interarrival Rate (in min) shift of 4000 hours	Interarrival Rate (in min) shift of 6000 hours
Family 1	China to Africa	3.35%	25.15%	1332	90.09	180.18	270.27
	China to Asia		61.95%	3280	36.59	73.17	109.76
	China to Europe		5.47%	290	413.79	827.59	1241.38
	China to Latin America		6.35%	337	356.08	712.17	1068.25
	China to North America		1.03%	55	2181.82	4363.64	6545.45
	China to Oceana		0.04%	2	60000.00	120000.00	180000.00
Family 2	China to Africa	16.70%	25.15%	6646	18.06	36.11	54.17
	China to Asia		61.95%	16369	7.33	14.66	21.99
	China to Europe		5.47%	1447	82.93	165.86	248.79
	China to Latin America		6.35%	1678	71.51	143.03	214.54
	China to North America		1.03%	273	439.56	879.12	1318.68
	China to Oceana		0.04%	10	12000.00	24000.00	36000.00
Family 3	China to Africa	15.37%	25.15%	6115	19.62	39.25	58.87
	China to Asia		61.95%	15060	7.97	15.94	23.90
	China to Europe		5.47%	1331	90.16	180.32	270.47
	China to Latin America		6.35%	1544	77.72	155.44	233.16
	China to North America		1.03%	251	478.09	956.18	1434.26
	China to Oceana		0.04%	9	13333.33	26666.67	40000.00
Family 4	China to Africa	57.20%	25.15%	22764	5.27	10.54	15.81
	China to Asia		61.95%	56066	2.14	4.28	6.42
	China to Europe		5.47%	4955	24.22	48.44	72.65
	China to Latin America		6.35%	5748	20.88	41.75	62.63
	China to North America		1.03%	933	128.62	257.23	385.85
	China to Oceana		0.04%	32	3750.00	7500.00	11250.00
Family 5	China to Africa	7.38%	25.15%	2938	40.84	81.69	122.53
	China to Asia		61.95%	7235	16.59	33.17	49.76
	China to Europe		5.47%	640	187.50	375.00	562.50
	China to Latin America		6.35%	742	161.73	323.45	485.18
	China to North America		1.03%	121	991.74	1983.47	2975.21
	China to Oceana		0.04%	5	24000.00	48000.00	72000.00

The different between the China manufacturing facility and the Puerto Rico manufacturing facility is the quantity of blood sugar strip vials and the percentage distribution amount. The quantity is based on the amount of customer type demand. Since China manufacturing facility will support the Low Income customer type and the Asia region demand is majority Low Income customer type then the input for the simulation will correspond to a greater number of products being manufactured in the China manufacturing facility than the Puerto Rico.

5.3 Section Simulation Inputs

Both manufacturing facilities will operate using similar manufacturing facilities; the differences will be demand allocations to different regions and the cellular manufacturing system design. Different family types will be allocated to different manufacturing cells. The next couple of section will describe the simulation; this is based on the manufacturing design.

Section: Simulation Dynamic Inputs based on VBA Coding

The dynamic inputs for the simulation are first entered into a workbook in Microsoft Excel and then with VBA coding the inputs are transferred into the Arena Simulation model. Dynamic inputs such as:

1) Family types
    a. Vial 1,2,3,4,& 5
2) Family type quantities to each of the six regions for each region
3) Sequence data: so if this product is to be allocated to manufacturing cell 1 then it should use machines from manufacturing cell 1.
4) Shift allocations to machines: some manufacturing cells are only open or operating from 1 shift whereas others are operating with shift type 2.

5) Capacity and processing times for each machine for each manufacturing cell

*The appendix contains both the VBA code and the Microsoft Excel workbook.

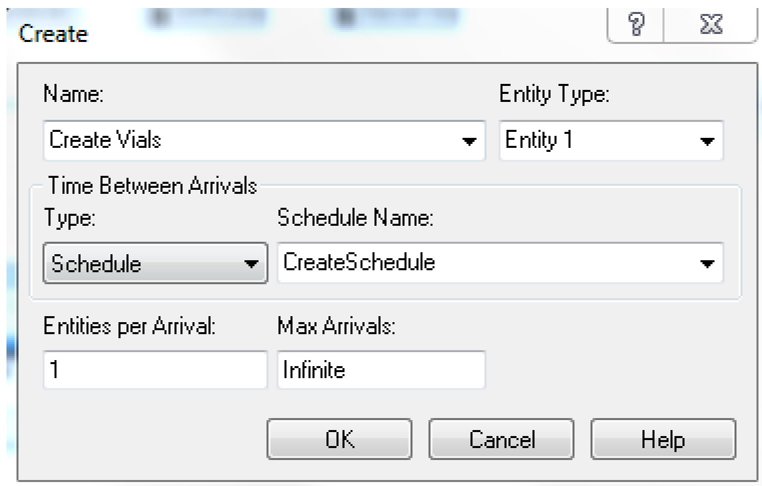

Figure 5.1 Entity Block

Figure 5.1 displays the creation of an entity. This process is done with VBA coding from Microsoft excel so that the user will need to enter inputs into each textbox into a table in Microsoft Excel. The name is the name of the block in Arena, the entity type is the name of the entity that is created, the type is how the entity will arrive, the value is the inter-arrival rate is based on a schedule, the unit is the time unit for each arrival, the entities per arrival is the amount of entities that will arrive at each instance, max arrivals is the amount of entities that will arrive for the year, and first creation is the when the first entity can arrive to the system. The simulation operates for a base time amount of 16 hours per day and then overtime is allocated every day to the system.

Overtime amount is different for Puerto Rico manufacturing facility and the China manufacturing facility.

5.3.1 How It Works

First an entity is created, and then it is allocated to any of the five different family types based the vial percentage distribution which was shown earlier in Table 5.9. The entity is assigned to one of the five family types based on a random number. The table show that 3.35% of total demand is from family type 1. So if the random number is between 0 and 0.0335 then family type 1 will be manufacturing. For this example the random number selected was 0.0222. The expression is a dynamic input because it is based on product demand of a manufacturing facility of a particular family type. The entity is a family type 1 so next a region needs to be assign to the entity. The region can be any of the six and is again based on an expression. Referring back to Chapter 4, the expression again is based on probabilities. There is a 25.15% change that the family type 1 entity will be manufactured to satisfy demand for an Africa customer. Once again based on a random number, if it is between 0 and 0.2515 then it is allocated to Africa demand. This example we say that the random is within the range. So the entity created is allocated to family type 1 to satisfy customer from Africa region.

5.3.2 Interarrival Rate

Ates (2013) study used the Interarrival Rate for five different family which is shown below:

$$\boldsymbol{InterarrivalRate_{Family(i)}} = \frac{\boldsymbol{AvailableWorkHours} * \frac{\boldsymbol{60min}}{\boldsymbol{1hr}}}{\boldsymbol{QuantitiesDemanded_{Family(i)}}} \qquad \textbf{(Equation 5.1)}$$

This study uses only one interarrival rate for the entire system, but uses Equation 5.1.

$$InterarrivalRate_{System} = \frac{4000 * \frac{60min}{1hr}}{158{,}194_{system}} = 1.51\ min$$

Based on the interarrival rate for the system, vials are determined based on an expression. The expression is displayed as a cumulative probability for each of the five vial types. Arrivals for this study are based on a schedule. The schedule is constructed so that vials will only arrive during the nominal 16 hour day. A manufacturing system may operate under only 16 hours of manufacturing time per day. This studies interarrival rate is based on a schedule, allowing arrivals only during the 16 hour schedule time.

5.3.3 Arena Simulation Components

Sequence: Once an entity has been assigned these parameters, a product sequence is assigned to the entity. The product sequence is based on which machines the entity will be manufacture on. The sequences are based on results from the mathematical model. Back to Chapter 4, the mathematical was developed and implemented to group demand coverage segments together to minimize the number of manufacturing cells. An entity can be allocated to different manufacturing cells, based on previous explanation the China manufacturing facility + 50% floating demand has a total of 7 manufacturing cells. Based on the output of the mathematical model the entity will be assigned to a manufacturing cell and thus assigned to a sequence. Different family types can be manufactured on the same machines within the same manufacturing cell. These family types are predetermined based on expression which is from demand allocation, referring back to Table 5.14. One of these blocks will be created in Arena for all entities, and this process is done by using VBA coding. Entity types are used in a set basic process, which is described later in this chapter.

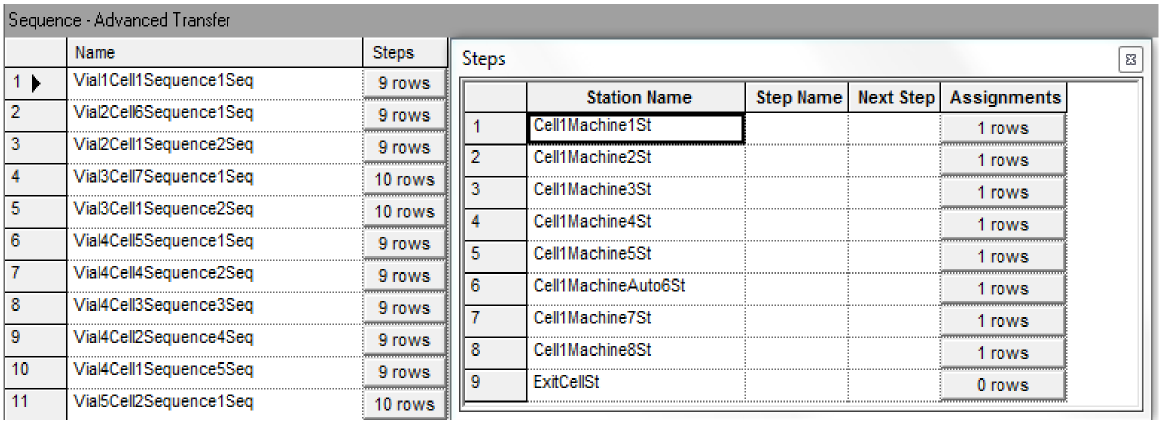

Figure 5.2 Sequences

Advanced Transfer Sequence is designed to group a sequence of events together. This study uses this technique to create a sequence for the manufacturing cells based on a machine sequence. Processing on machine 1 will happen before processing on machine 2 and so on. Shown below is the advanced transfer sequence for Vial1, Cell1 which is called Vial1Cell1Sequence1Seq. The sequence is Machine1, Machine2, Machine3, Machine4, Machine5, MachineAuto6, Machine7, Machine8, and then the product exits the sequence.

Resource List: The resource list is created to illustrate the different machines in the process. If a manufacturing cell is created and used then the correct machines must be created and used for those produces and in that manufacturing cell. These inputs are also entered into the Arena simulation model by using VBA coding from Microsoft Excel. These values are determined from the mathematical model results, described earlier in this chapter. In this study, Arena simulation model resources are used in advanced transfer sequences and basic process sets (these are described later in this chapter), which are used in the manufacturing process of individual manufacturing cells.

Queue List: The queue list is created to show how the entities perform within the resources. There performances metrics include waiting time, processing time, time in manufacturing system, etc. Statistical analysis will be performed on these metrics to demonstrate the capabilities of the manufacturing system.

Basic process sets and Advanced Sets: is designed to group a set of similar items together such as resources, queues, entities types, etc. so that the simulation model can call the set instead of calling all of the individual items.

Station: A station is an advanced transfer block that is established to get a group of products to a location. This study uses multiple station blocks to connect sub-models together. A sub-model will end with a route block and then start with a station block. So all products are send from a location in one sub-model to the station of the next sub-model.

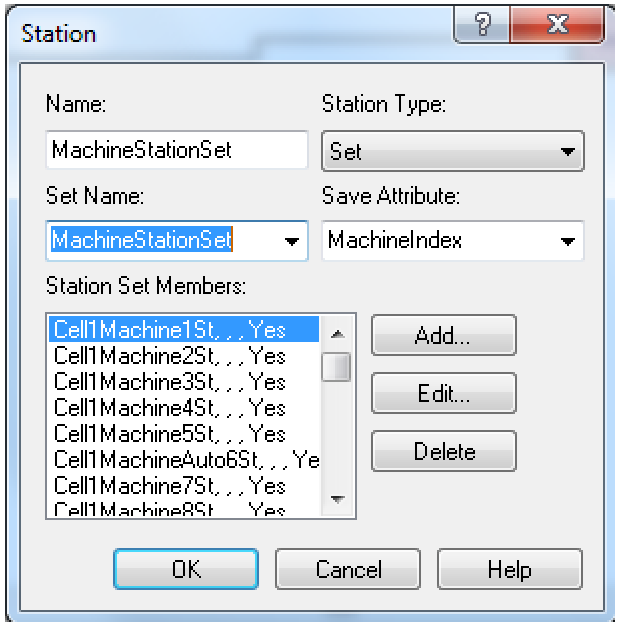

Figure 5.3 Station Block

Route**:** A route block is used to connect multiple sub-models together. This logic is done by routing the entities to a location of the next sub-model where is station is used. Parameters such as time can be used for how long this operation takes for the products to move from one area of the manufacturing facility to another area of the manufacturing facility. This study allocates a time value of zero to move the products.

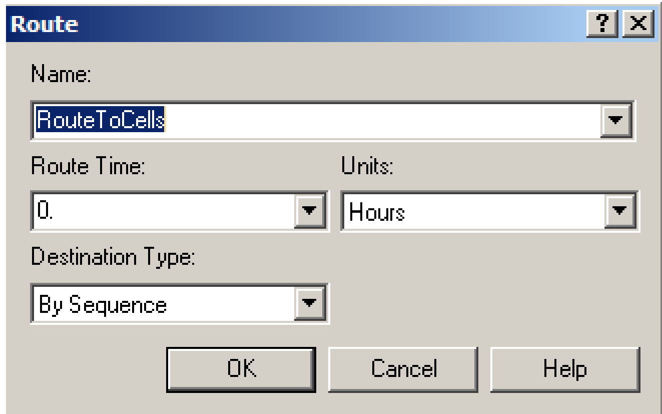

Figure 5.4 Route Block

Seize**:** The seize block is used to allocate one or multiple resources to and entity. This study uses the seize block to allocated multiple machines to one entities. The seize block will send the entity to the correct queue to wait until the manufacturing process can take place.

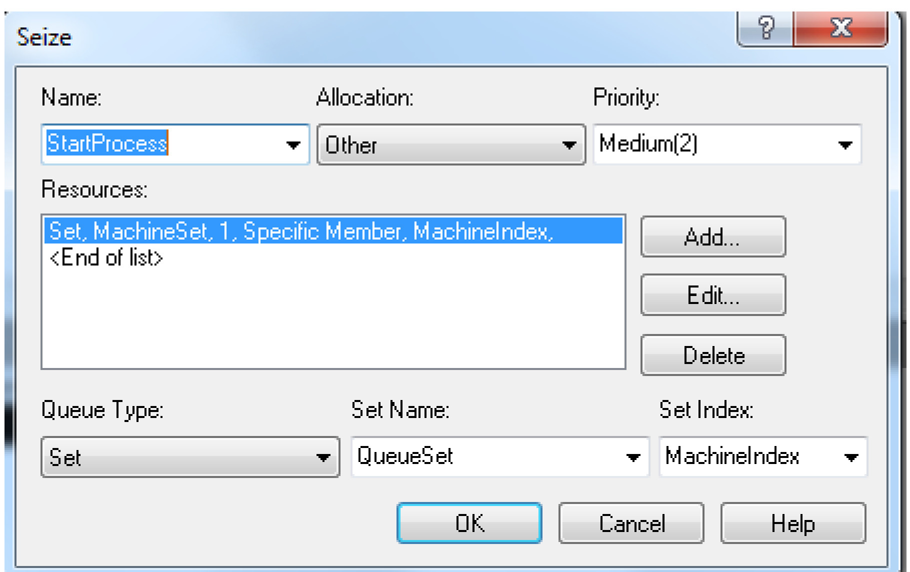

Figure 5.5 Seize Block

Process**:** A process block is used to used illustrate the process that is happening during the manufacturing cycle. First the entity will be seize into the queue and then will be delayed until manufacturing starts. The resource for the process is described in the resources screen, where a set of machines is used. The process block has variation with the process time for the operation, in this instance there is a triangular distribution with 90% of the processing time, 100% of the processing time, and 110% of the processing time so extra time was needed to manufacture the entity.

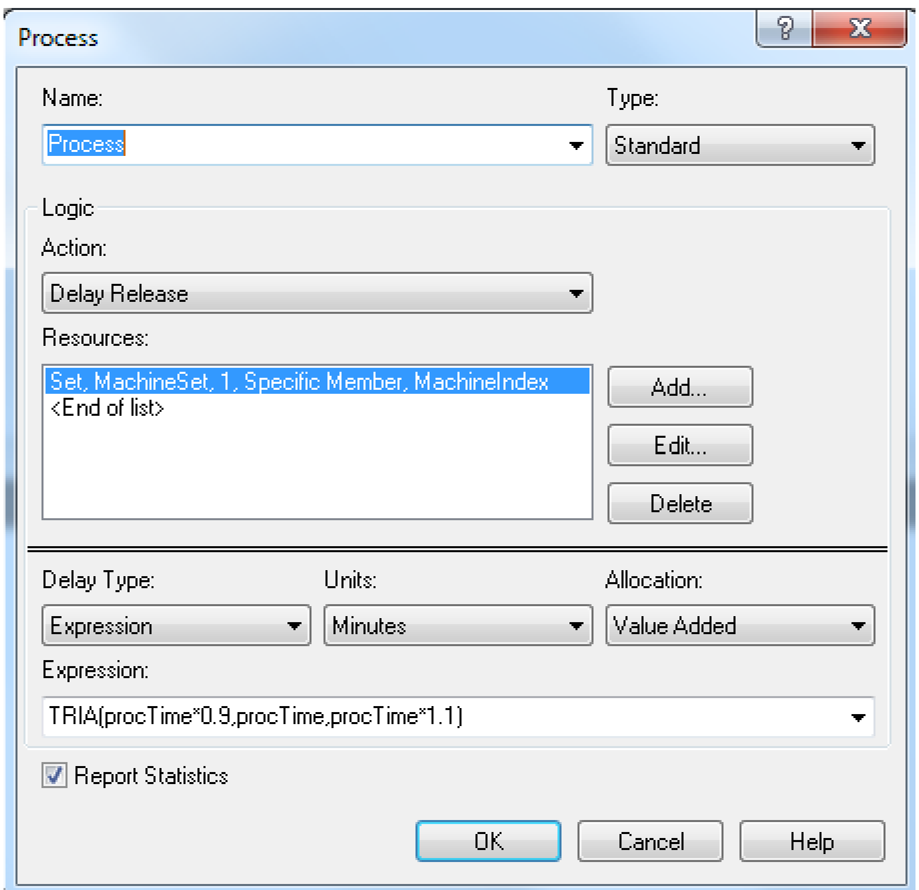

Figure 5.6 Process Block

The dispose block gets rid of the entities once they have finished the manufacturing process so that calculation such as time in system can be computed. Usually the dispose block is placed at the end of the simulation.

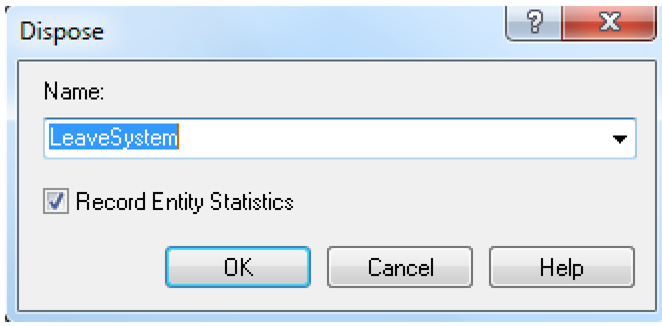

Figure 5.7 Dispose Block

Assign Block**:** This assign block assigns attributes such as part index which is based on an expression and from the expression an entity can be given a Vial Type.

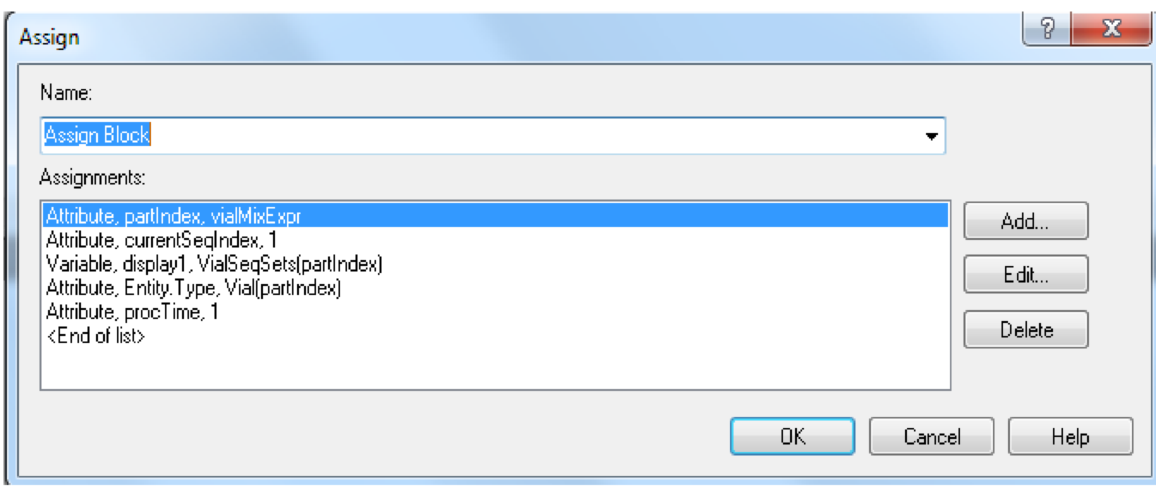

Figure 5.8 Assign Block

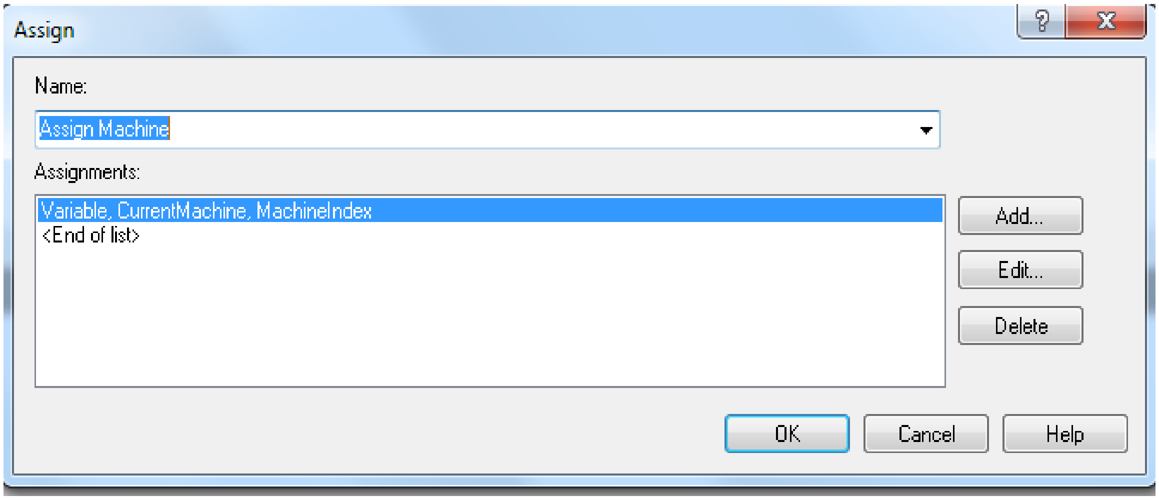

Figure 5.9 Assign Machine

This assign block gives the starting machine for the entity, and for this study all entities will start manufacturing with machine 1 for their desired manufacturing cell.

5.4 Sub-Models

All of these different types of blocks are used for the simulations models. The blocks are arranged in a template model and then values for the blocks are imported into the arena simulation model using VBA coding. The arena simulation model is made up of three different sub-models. Each sub-model corresponds to a different operation within the overall simulation model. The simulation structure is shown below with a description of each of the three sub-models.

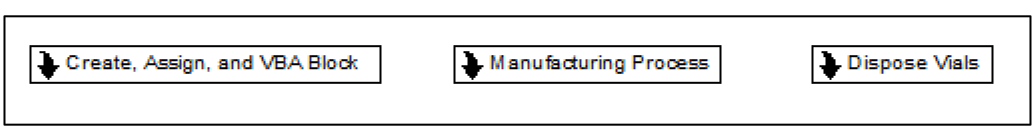

Figure 5.10 Top Level of Sub-Models

5.4.1 Sub-Model 1

The three sub-models obtain to different process and characteristics of the complete simulation model. The first sub-model; Create, Assign, and VBA Block is described as creating all entities and assign each creation its attributes. Once all attributes have been assigned to the entity then it will enter a route block to go to the next sub-model. If there are multiple manufacturing cells for a product family type then through queueing theory approach which is based on shift type allocation and queue size. Once all attributes have been assigned to the entity within the VBA block then the entity enters into the Route Block to transfer it into the next sub-model. The diagram below describes the process flow for the manufacturing system.

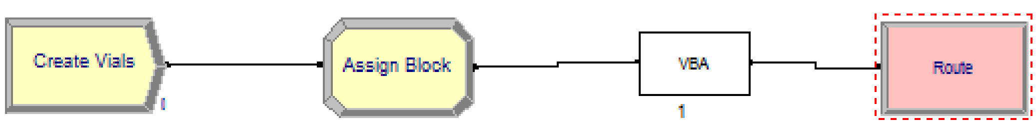

Figure 5.11 Create, Assign, and VBA Block Sub-Model

5.4.2 Sub-Model 2

The second sub-model called Manufacturing Process is described as processing all of the entities into their required manufacturing cells based on sequences and manufacturing cell allocation. Entities start the sub-model with a station that is required to create a set of machines that each manufacturing cell consist of. Then the entity enters into a seize block to wait until they are called to the desired queue. Once an entity is called upon they wait in the queue until manufacturing of the entity happens in the processing block. After processing the entities enter a route block to be transferred to the next sub-model. The figure below displays the sub-model.

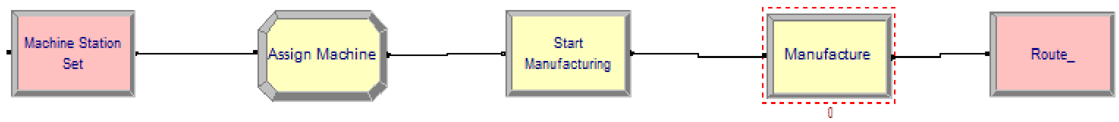

Figure 5.12 Manufacturing Process Sub-Model

5.4.3 Sub-Model 3

The final sub-model called dispose vials is described as disposing all of the entities that were created to end the simulation model. The sub-model starts with a station block so that the route block of the previous sub-model can transfer the entities to this sub-model. The reason for disposing all of the entities is to collect calculations such as entity time in system. The figure below displays the Dispose Vial sub-model.

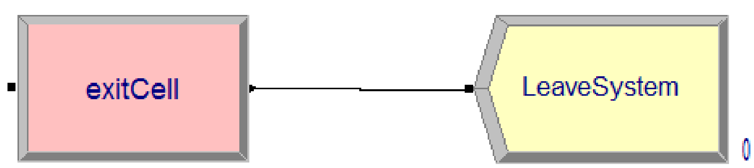

Figure 5.13 Dispose Vials Sub-Model

The three sub-model described above is the simulation template for this study. The logic of the simulation was used in Ates (2013) fast manufacturing system design. This study uses the capability of VBA coding to call data into the template model. The simulation model was ran for multiple replications based on manufacturing cell groupings for shifts lengths of either 2000 manufacturing hours/year, 4000 manufacturing hours/year, or 6000 manufacturing hours/year. The simulation run results is shown in a later chapter called Results.

The VBA Coding created a connection between Microsoft Excel and Arena Simulation Software. User imputed values into Microsoft Excel and then those values where read into Arena Simulation template model. The Microsoft Excel file is located in the appendix.

5.5 Scheduling Approach for Queue

The scheduling approach is used to allocate queue sizes for a dynamic manufacturing system. For this study with the China manufacturing facility + 50% floating, there are a total of seven manufacturing cells; 5 operating with two shifts and two operating with one shift. These seven manufacturing cells operate with a combination of 13 different coverage segments from the five product families. Based on utilization calculations (shown in Chapter 4), manufacturing cell groupings, and manufacturing system time queuing theory was used to determine at what time a manufacturing cell would open for operation for a vial type. For a manufacturing cell to obtain its desired utilization total and for the demand coverage probabilities the system must allocate times to when a vial type can be processed in a manufacturing cell.

Referring to Table 5.5.1 below and tables in Chapter 4, the product families need to contribute there expected utilization to the manufacturing cells that they are dedicated to. Starting with family type 1 and family type 5, both of these families operate with only one manufacturing cell for the entire two shifts or 16 hour processing time. Family type 1 allocates 18.4% to manufacturing cell 1 and Family type 5 allocates 40.6% to manufacturing cell 2. Both of these families operate for the full 16 hour manufacturing time. Next for the China manufacturing, family type 2 is allocated to the desired manufacturing cells for each coverage segment, where family type 2 has two coverage segments. Coverage segment 1, operates under one shift type and cover segment 2 operates for two shifts. Based on tables 5.5.1 and 5.5.2 below, coverage segment 1 is allocated to manufacturing cell 6 and coverage segment 2 is allocated to manufacturing cell 1. Manufacturing cell 6, operates for only 8 manufacturing hours/day, but vials can be allocated to manufacturing cell 6 up to time 552.96 (min). So after time 480 min (time when 1st shift is over so manufacturing cell 6 stops production) vials can be allocated to manufacturing cell 6 until time 552.96 min if the queue size for manufacturing cell 6 is less than the queue size for the manufacturing cell 1 (coverage segment 2 allocation). If the queue size is less than the vial will be allocated to manufacturing cell 6 and will wait until the following day when manufacturing cell 6 is open for production again. After time 552.96 all vials will be allocated to manufacturing cell 1 for the remainder of the day. Next for the China manufacturing, family type 3 is allocated to the desired manufacturing cells for each coverage segment, where family type 3 has two coverage segments. Coverage segment 1, operates under one shift type and coverage segment 2 operates for two shifts. Based on tables 5.15 and 5.16 below, coverage segment 1 is allocated to manufacturing cell 7 and coverage segment 2 is allocated to manufacturing cell 1. Manufacturing cell 7, operates for only 8 manufacturing hours/day, but vials can be allocated to manufacturing cell 6 up to time 624.96 (min). So after time 480 min (time when 1st shift is over so manufacturing cell 7 stops production) vials can be allocated to manufacturing cell 7 until time 624.96 min if the queue size for manufacturing cell 7 is less than the queue size for the manufacturing cell 1 (coverage segment 2 allocation). If the queue size is less than the vial will be allocated to manufacturing cell 7 and will wait until the following day when manufacturing cell 7 is open for production again. After time 624.96 all vials will be allocated to manufacturing cell 1 for the remainder of the day. Family type 4 is assigned to five different manufacturing cells which operate for two shifts. To introduce different processing time amounts, coverage segment 1 for this family will be open for the entire 16 hours. Coverage segment 2 will not open for production for vial 4 until time 12.98 minutes from the start of production, thus starting at time 12.98 in terms of minutes. Coverage segment 2 is allocated to manufacturing cell 4, so manufacturing cell 4 will start production for vial 4 at time 12.98 and will operate until the end of the period or 16 hours. With this delay start, production allocation of vial 4 will be sent to manufacturing cell 4 for a total of 15.78 hours of the total 16 hours for each day. Coverage segment 3 will not open for production of vial 4 until time 189.6 minutes from the start of production, thus starting at time 189.6 in terms of minutes. Coverage segment 3 is allocated to manufacturing cell 3, so manufacturing cell 3 will start production of vial 4 at time 189.6 and will operate until the end of the period or 16 hours. With this delay start, production allocation of vial 4 will be sent to manufacturing cell 3 for a total of 12.84 hours of the total 16 hours for each day. Coverage segment 4 will not open for production of vial 4 until time 654.816 minutes from the start of production, thus starting at time 654.816 in terms of minutes. Coverage segment 4 is allocated to manufacturing cell 2, so manufacturing cell 2 will start production of vial 4 at time 654.816 and will operate until the end of the period or 16 hours. With this delay start, production allocation of vial 4 will be sent to manufacturing cell 2 for a total of 5.09 hours of the total 16 hours for each day. Coverage segment 5 will not open for production of vial 4 until time 909.696 minutes from the start of production, thus starting at time 909.696 in terms of minutes. Coverage segment 5 is allocated to manufacturing cell 1, so manufacturing cell 1 will start production of vial 4 at time 909.696 and will operate until the end of the period or 16 hours. With this delay start, production allocation of vial 4 will be sent to manufacturing cell 1 for a total of 0.84 hours of the total 16 hours for each day. Family 2 operates with two shifts, the first coverage segment operating at shift type 1 and the second operating at shift type 2. Based on the size of each queue; for the first shift, a vial can be manufactured in either manufacturing cell 6 or manufacturing cell 1. The selected manufacturing cell is the queue with fewer vials in the queue. So if there are 3 vials in machine 1 cell 1 queue and 7 vials in machine 1 cell 6 queue then cell 1 will be selected to manufacture the vial and the vial will be added to machine 1 cell 1 queue. For all vials arriving during shift type 2 or hours 9-16 will be allocated to either of the two manufacturing cells depending on queue size for each manufacturing cell. If the queue size for manufacturing cell 6 is less than the queue size for manufacturing cell 1, then the vial will be processed the next day because manufacturing cell 6 operates only at one shift. The same procedure is applied to family type 3; where vials can go to either manufacturing cell 1 or manufacturing cell 7 and is dependent on the minimum queue for both manufacturing cells. Again manufacturing cell 7 will operate only at shift type 1, so if vials are allocated to this manufacturing cell during the second shift then they will wait until the following day to be processed. Family type 1 and 5 will allocate vials for the entire two shift period for only one manufacturing cell for each; manufacturing cell 1 for family type 1 and manufacturing cell 2 for family type 5. Based on combinations that have been selected from the mathematical model the simulation with the queuing theory should produce similar resource utilization results. These values are shown in the simulation chapter in section 5.8.1-5.8.3.

Table 5.15 Expanded 2011 Scheduling Approach Queue China Facility

Queueing Theory Manufacturing Cell Times						
	Coverage Segment	1	2	3	4	5
Family 1	Utilization	18.4%				
	Start time(hr)	13.056				
	Start time (min)	783.36				
	Total Production Time (hr)	2.94				
Family 2	Utilization	99.5%	42.4%			
	Start time(hr)	0.04	9.216			
	Start time (min)	2.4	552.96			
	Total Production Time (hr)	7.96	6.78			
Family 3	Utilization	99.1%	34.9%			
	Start time(hr)	0.072	10.416			
	Start time (min)	4.32	624.96			
	Total Production Time (hr)	7.93	5.58			
Family 4	Utilization	100.0%	98.7%	80.3%	31.8%	5.2%
	Start time(hr)	0	0.216	3.16	10.9136	15.1616
	Start time (min)	0	12.96	189.6	654.816	909.696
	Total Production Time (hr)	16.00	15.78	12.84	5.09	0.84
Family 5	Utilization	40.6%				
	Start time(hr)	9.512				
	Start time (min)	570.72				
	Total Production Time (hr)	6.49				

Table 5.15 describes the amount of production that each family must achieved to sustain its desired utilization. To fulfill capacity for the entire day, a family must be allocated for all production times so a coverage segment must start at time zero and end at time 960 (1 day or 16 manufacturing hours). Based on these components, Table 5.16 is the reality production schedule for the manufacturing system.

Table 5.16 Expanded 2011 Scheduling Approach Queue China Facility

Simulation Queueing Theory Manufacturing Cell Times						
	Coverage Segment	1	2	3	4	5
Family 1	Utilization	18.4%				
	Start time(hr)	0				
	Start time (min)	0				
	End time (min)	0				
	Total Production Time (hr)	16.00				
Family 2	Utilization	99.5%	42.4%			
	Start time(hr)	0	0			
	Start time (min)	0	0			
	End time (min)	552.96	960			
	Total Production Time (hr)	8.00	16.00			
Family 3	Utilization	99.1%	34.9%			
	Start time(hr)	0	0			
	Start time (min)	0	0			
	End time (min)	624.96	960			
	Total Production Time (hr)	8.00	16.00			
Family 4	Utilization	100.0%	98.7%	80.3%	31.8%	5.2%
	Start time(hr)	0	0.216	3.16	10.9136	15.1616
	Start time (min)	0	12.96	189.6	654.816	909.696
	End time (min)	960	960	960	960	960
	Total Production Time (hr)	16.00	15.78	12.84	5.09	0.84
Family 5	Utilization	40.6%				
	Start time(hr)	0				
	Start time (min)	0				
	End time (min)	960				
	Total Production Time (hr)	16.00				

2011 Expanded Business Strategy Puerto Rico + 50% Floating manufacturing system scheduling approach queue and 2010 Standard Business Strategy Puerto Rico manufacturing system schedule approach queue data, refer to appendix.

5.6 Manufacturing System Overtime

Established in the VBA coding, this study allows for the manufacturing system to operate for overtime amounts. Due to this study focusing on covering current demand, overtime component is not used.

5.7 Welch Warm-up Period Analysis

The warm-up period analysis is based on entities that are in the system. A manufacturing system is considered stable when the number of entities in the system is constant. An unstable manufacturing system is when the number of entities in the system continues to increase. To get the system to a steady state, we must allocate a warm-up period to the system. The warm-up period is the amount of time that the manufacturing system needs to operate until steady state manufacturing is reached. In this study, Welch's algorithm is used to determine the warm-up period. To test the corresponding warm-up period for each manufacturing system, the 2011 Expanded China + 50% Floating manufacturing facility simulation is run for 2500 days or ten years with 10 different simulation replications. The warm-up period for the manufacturing system is based on Welch's warm-up analysis method. The method is based on the moving average for the number of entities in the manufacturing system. Figure 5.14 represents the 2011 Expanded China + 50% floating manufacturing facility. The manufacturing is considered stable with an upper limit moving average of 288.43 entities and a lower limit moving average of 172.39 entities. Analyzing the volatility of system and concluding that the system is stable, this manufacturing system will operate with a warm-up period of 25 manufacturing days. The system is based on a moving average of a time period referred to the Window Length. From Ates (2013) the moving average is based on Equations 5.2 and 5.3:

$$\boldsymbol{Moving\ Average_i} = \frac{\left(\sum_{i=1}^{2i-1} \boldsymbol{Moving\ Average}_{|-i+1|}\right)}{(\mathbf{2}*(\boldsymbol{i}-\mathbf{1})+\mathbf{1})} \qquad \textbf{(Equation 5.2)}$$

$$Where\ i \leq Window\ Length$$

$$\boldsymbol{Moving\ Average_i} = \frac{\sum_{i-10}^{i+10} \boldsymbol{Moving\ Average}_{|-i+1|}}{(\mathbf{2}*\boldsymbol{Window\ Length})+\mathbf{1}} \qquad \textbf{(Equation 5.3)}$$

$$Where\ i > Window\ Length$$

The Window Length is 10 for Figure 5.14, so the moving average is based on the last Window Length * 2 + 1. For the manufacturing system this study used a window length of 10 to determine warm-up period as shown in Figure 5.14. This study also used a window length of 100 to determine in the manufacturing system is stable as shown in figure 5.15. Figures 5.16- 5.19 shown the warm-up period analysis and for steady state parameters for the other two manufacturing systems but are based only on a three year period.

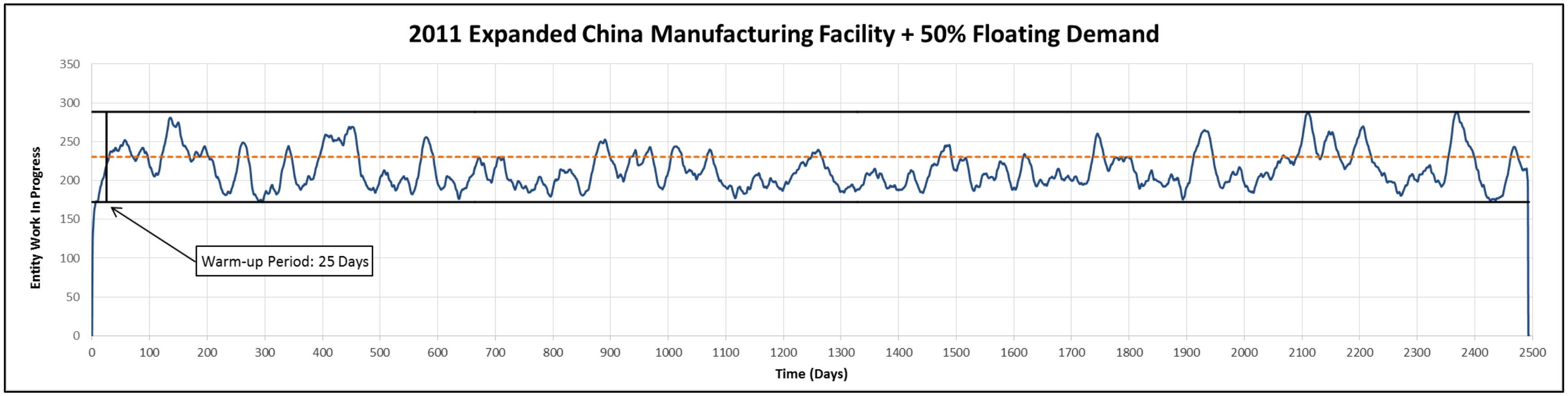

Figure 5.14 Expanded China Manufacturing Facility + 50% Warm-up Period

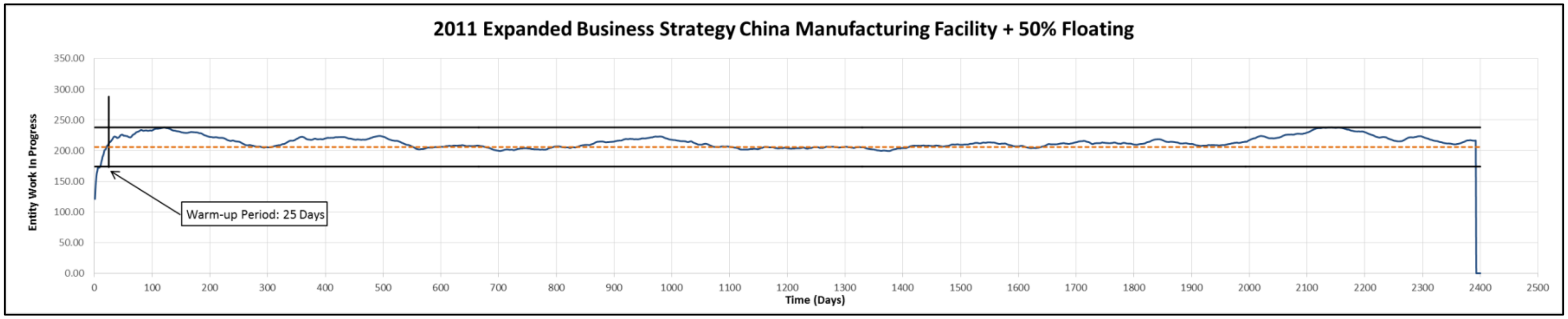

Figure 5.15 2011 Expanded Business Strategy China Manufacturing Facility + 50% Floating

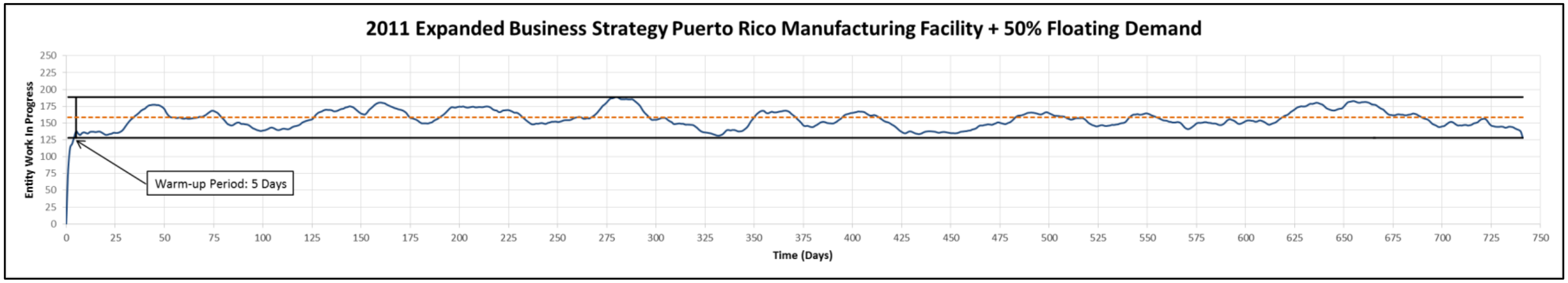

Figure 5.16 2011 Expanded Business Strategy Puerto Rico Manufacturing Facility + 50% Floating Demand

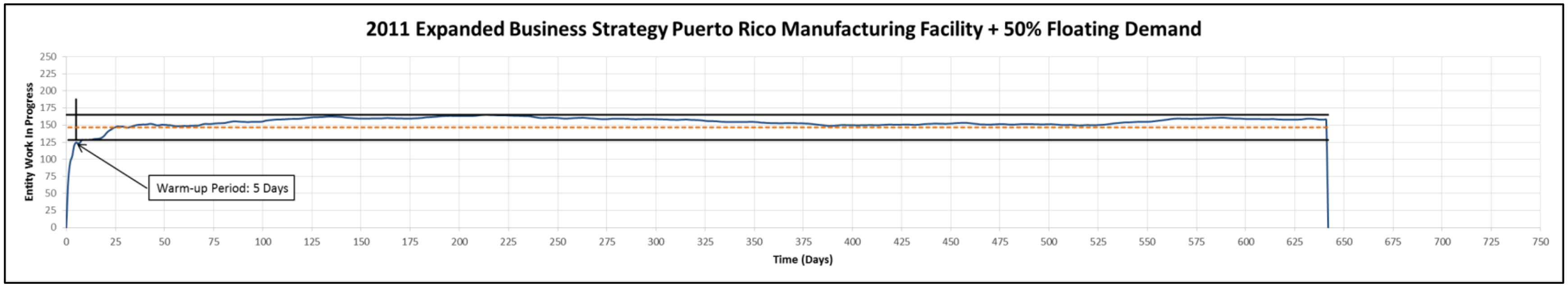

Figure 5.17 2011 Expanded Business Strategy Puerto Rico Manufacturing Facility + 50% Floating Demand

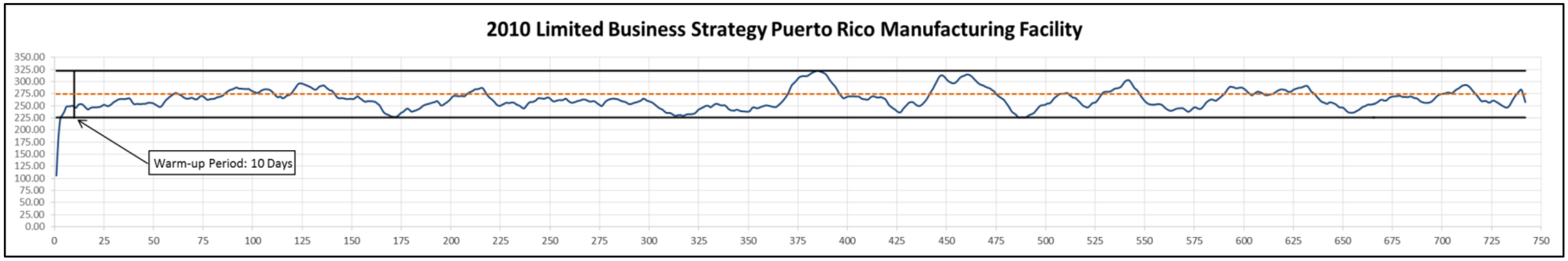

Figure 5.18 2010 Limited Business Strategy Puerto Rico Manufacturing Facility

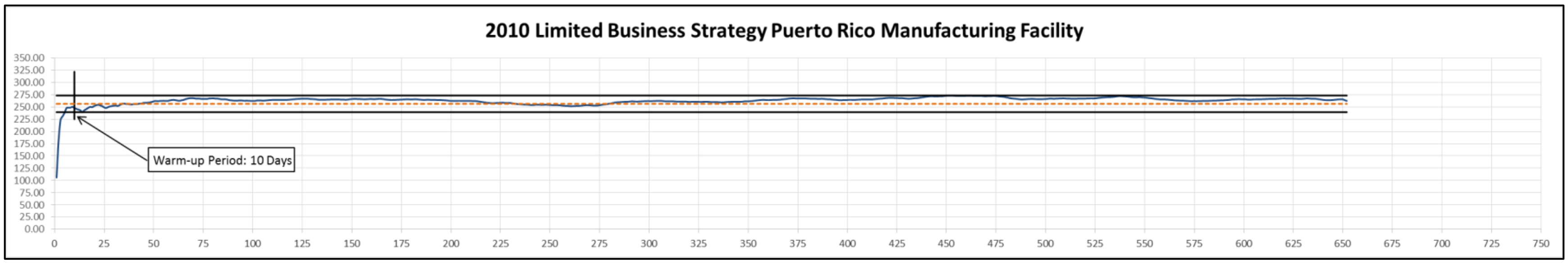

Figure 5.19 2010 Limited Business Strategy Puerto Rico Manufacturing Facility

5.8 Simulation Results

This study operates from year to year basis so the simulation for statistics was ran for duration of one calendar year or 250 manufacturing days, with each day operating for 16 manufacturing hours or two shifts. All simulations were run for 10 replications.

5.8.1 Limited 2010 Puerto Rico Business Strategy Manufacturing Facility

Based on the number of entities that enters and exits the manufacturing system, in terms of batches, and these figures are compared to the expected demand, which are extremely close. Entities that enter in the system will exit the system within a range of 270.59 minutes to 571.96 minutes, referring to Table 5.17. Table 5.17 displays the bottleneck resource utilization (Floating bottleneck for each manufacturing cell) and compares the resource utilization to the OPL result that was described in Chapter 4. Based on bottleneck calculations, this manufacturing system has a floating bottleneck operation resulting in the system using three different resource bottleneck machine; Machine Auto 6, Machine Man 6, and Machine 9.

Table 5.17 Limited 2010 Business Strategy Puerto Rico Simulation Statistics

Limited 2010 Business Strategy Puerto Rico Manufacturing Facility System Entity Simulation Statistics							
Vial Type	Entity Number that Enter the System	Entity Number that Exit the System	Entity Total Time in System (Average in Min)	Entity Value Added Time (Average in Min)	Entity Wait Time (Average in Min)	Entity Work In Progress in the System (Average)	Entity Work In Progress in the System (max)
Vial 1	4,164	4,164	298.94	130.67	168.27	5.18	30
Vial 2	20,764	20,764	270.59	130.69	139.90	23.42	78
Vial 3	18,956	18,956	494.87	181.51	313.36	39.11	109
Vial 4	70,883	70,883	571.96	130.68	441.28	168.95	316
Vial 5	9,171	9,171	527.92	181.50	346.41	20.18	81
Total	123,938	123,938					

Table 5.18 Limited 2010 Business Strategy Puerto Rico Bottleneck Resource Utilization

Limited 2010 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Bottleneck Resouce Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 6 Auto	98.60%	96.33%	2.356%
Cell 2 Machine 9	84.40%	79.25%	6.498%
Cell 3 Machine Man 6	97.10%	93.32%	4.051%
Cell 4 Machine Man 6	99.60%	87.16%	14.273%
Cell 5 Machine Man 6	99.90%	95.10%	5.047%
Cell 6 Machine Man 6	99.50%	97.40%	2.156%
Cell 7 Machine Man 6	100.00%	100.00%	0.000%
Cell 8 Machine 9	100.00%	97.49%	2.575%

Table 5.19 displays the bottleneck resource queue statistics for the simulation. The resource queue average entity number waiting ranges from 3.73 entities in manufacturing cell 2 to 15.42 in manufacturing cell 7.

Table 5.19 Limited 2010 Business Strategy Puerto Rico Bottleneck Resource Statistics

Limited 2010 Business Strategy Puerto Rico Manufacturing Facility System Bottleneck Resource Statistics					
Bottleneck Resource	Queue Number Waiting (average)	Queue Number Waiting (max)	Bottleneck Resource Queue Waiting Time (Average in Min)	Bottleneck Resource Queue Waiting Time (Max in Min)	Bottleneck Resource Total Number Seized (Average)
Cell 1 Machine Auto 6	8.54	57	112.67	720.63	18321
Cell 2 Machine 9	3.73	34	79.7984	591.81	11394
Cell 3 Machine Man 6	9.37	59	127.56	741.27	17715
Cell 4 Machine Man 6	7.73	52	112.69	652.94	16637
Cell 5 Machine Man 6	9.91	57	132.39	712.5	18059
Cell 6 Machine Man 6	12.62	77	164.56	968.3	18483
Cell 7 Machine Man 6	15.42	61	384.85	1699.97	9656
Cell 8 Machine 9	8.87	40	308.02	1599.92	6962

Table 5.20 displays the system results based on entity work in progress (average) of 256.84 entities and the maximum number of entities in the system of 458.

Table 5.20 Limited 2010 Business Strategy Puerto Rico Total System Statistics

Limited 2010 Business Strategy Puerto Rico Manufacturing Facility System Total System Statistics	
Value Added Time Per Entity (Average in min)	17.2864
Total Time Per Entity (Average in min)	18.1817
Entity Work in Progress (Average)	256.84
Entity Work in Progress (Max)	439

5.8.2 Expanded 2011 Business Strategy China Manufacturing Facility

Based on the number of entities that enters and exits the manufacturing system, in terms of batches, and these figures are compared to the expected demand, which are extremely close. Entities that enter in the system will exit the system within a range of 213.73 minutes to 503.06 minutes. Table 5.21 displays the bottleneck resource utilization (Machine 1 for each manufacturing cell) and compares the resource utilization to the OPL result that was described in Chapter 4. Based on bottleneck calculations, this manufacturing system has a bottleneck machine in operation 1.

Table 5.21 Expanded 2011 Business Strategy China Simulation Statistics

Expanded 2011 Business Strategy China Manufacturing Facility System + 50% Floating Entity Simulation Results							
Vial Type	Entity Number that Enter the System	Entity Number that Exit the System	Entity Total Time in System (Average in Min)	Entity Value Added Time (Average in Min)	Entity Wait Time (Average in Min)	Entity Work In Progress in the System (Average)	Entity Work In Progress in the System (max)
Vial 1	5,288	5,286	306.08	122.19	183.89	6.74	28
Vial 2	26,420	26,412	457.46	122.21	335.25	50.38	141
Vial 3	24,305	24,292	503.06	164.58	338.48	50.95	143
Vial 4	90,710	90,705	216.18	122.21	138.98	98.72	190
Vial 5	11,649	11,649	213.73	164.56	49.17	10.37	36
Total	158,372	158,344					

Table 5.22 Expanded 2011 Business Strategy China Bottleneck Resource Utilization

Expanded 2011 Business Strategy Comparison between China Manufacturing Facility: Bottleneck Resource Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 1	98.70%	99.97%	1.270%
Cell 2 Machine 1	71.40%	69.98%	2.029%
Cell 3 Machine 1	80.30%	90.27%	11.045%
Cell 4 Machine 1	98.30%	99.96%	1.661%
Cell 5 Machine 1	100.00%	100.00%	0.000%
Cell 6 Machine 1	99.50%	99.26%	0.242%
Cell 7 Machine 1	99.10%	98.34%	0.773%

Table 5.23 displays the bottleneck resource queue statistics for the simulation. The resource queue average entity number waiting ranges from 5.2016 entities in manufacturing cell 2 to 20.0498 in manufacturing cell 6.

Table 5.23 Expanded 2011 Business Strategy China Bottleneck Resource Statistics

Limited 2010 Business Strategy Puerto Rico Manufacturing Facility System Bottleneck Resource Statistics					
Bottleneck Resource	Queue Number Waiting (average)	Queue Number Waiting (max)	Bottleneck Resource Queue Waiting Time (Average in Min)	Bottleneck Resource Queue Waiting Time (Max in Min)	Bottleneck Resource Total Number Seized (Average)
Cell 1 Machine 1	20.8666	76	176.76	636.2	28320
Cell 2 Machine 1	5.2016	36	62.9607	299.69	19824
Cell 3 Machine 1	13.2115	44	123.98	369.48	25573
Cell 4 Machine 1	17.258	48	146.26	403.01	28318
Cell 5 Machine 1	17.6954	49	149.92	413.04	28327
Cell 6 Machine 1	20.0498	76	341.9	1569.27	14059
Cell 7 Machine 1	18.7995	76	323.79	1517.03	13925

Table 5.24 displays the system results based on entity work-in-progress (average) of 217.17 entities and the maximum number of entities in the system of 408.

Table 5.24 Expanded 2011 Business Strategy China Total System Statistics

Expanded 2011 Business Strategy China Manufacturing Facility System + 50% Floating Total System Statistics	
Value Added Time Per Entity (Average in min)	16.02
Total Time Per Entity (Average in min)	17.42
Entity Work in Progress (Average)	217.17
Entity Work in Progress (Max)	408.00

5.8.3 Expanded 2011 Business Strategy Puerto Manufacturing Facility

Based on the number of entities that enters and exits the manufacturing system, in terms of batches, and these figures are compared to the expected demand, which are extremely close. Entities that enter in the system will exit the system within a range of 205.73 minutes to 427.57 minutes. Table 5.25 displays the bottleneck resource utilization (Machine 1 for each manufacturing cell) and compares the resource utilization to the OPL result that was described in Chapter 4. Based on bottleneck calculations, this manufacturing system has a bottleneck machine in operation 1.

Table 5.25 Expanded 2011 Business Strategy Puerto Rico Simulation Statistics

Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility System + 50% Floating Simulation Results							
Vial Type	Entity Number that Enter the System	Entity Number that Exit the System	Entity Total Time in System (Average in Min)	Entity Value Added Time (Average in Min)	Entity Wait Time (Average in Min)	Entity Work In Progress in the System (Average)	Entity Work In Progress in the System (max)
Vial 1	3,632	3,632	279.74	130.66	149.08	4.23	17
Vial 2	18,210	18,210	205.73	130.67	75.0606	15.61	57
Vial 3	16,691	16,691	267.88	173.04	94.8372	18.63	51
Vial 4	62,082	62,066	427.57	130.68	296.88	110.63	229
Vial 5	8,001	8,001	247.95	173.06	74.886	8.27	32
Total	108,616	108,600					

Table 5.26 Expanded 2011 Business Strategy Puerto Rico Bottleneck Resource Utilization

Expanded 2011 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Bottleneck Resource Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 1	99.70%	99.68%	0.020%
Cell 2 Machine 1	91.50%	94.98%	3.664%
Cell 3 Machine 1	85.30%	88.84%	3.985%
Cell 4 Machine 1	99.70%	99.82%	0.120%
Cell 5 Machine 1	100.00%	99.97%	0.030%

Table 5.27 displays the bottleneck resource queue statistics for the simulation. The resource queue average entity number waiting ranges from 7.98 entities in manufacturing cell 2 to 20.17 in manufacturing cell 5.

Table 5.27 Expanded 2011 Business Strategy Puerto Rico Bottleneck Resource Statistics

Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility System + 50% Floating Bottleneck Resource Statistics					
Bottleneck Resource	Queue Number Waiting (average)	Queue Number Waiting (max)	Bottleneck Resource Queue Waiting Time (Average in Min)	Bottleneck Resource Queue Waiting Time (Max in Min)	Bottleneck Resource Total Number Seized (Average)
Cell 1 Machine 1	16.62	49	141.23	405.87	28,240
Cell 2 Machine 1	7.98	63	71.1231	529.02	26,904
Cell 3 Machine 1	10.40	48	99.05	398.18	25,170
Cell 4 Machine 1	19.80	54	335.92	926.75	14,139
Cell 5 Machine 1	20.17	54	341.81	936.56	14,155

Table 5.28 displays the system results based on entity work in progress (average) of 157.38 entities and the maximum number of entities in the system of 288.

Table 5.28 Expanded 2011 Business Strategy Puerto Rico Total System Statistics

Expanded 2011 Business Strategy Puerto Rico Manufacturing Facility System + 50% Floating Total System Statistics	
Value Added Time Per Entity (Average in min)	17.05
Total Time Per Entity (Average in min)	18.99
Entity Work in Progress (Average)	157.38
Entity Work in Progress (Max)	288.00

5.9 One-way Anova Statistical Analysis

The Anova statistical analysis test was conducted to determine if there was statistical difference between the means for two cases;

1) Work in Progress (WIP) for the complete manufacturing system
2) Flow Time for the complete manufacturing system

The null hypothesis states that all the means are equal whereas the alternative hypothesis that at least two of the means are different. Table 5.29-5.32 displays the data for the WIP Anova test that was conducted in Microsoft Excel. Additional Anova tests for individual vials are displayed in the appendix.

$$\mathbf{H}_{o}: \mu_{2010\ PR} = \mu_{2011\ China} = \mu_{2011\ PR}$$

$$\mathbf{H}_{a}: \textit{atleast two are unequal}\ (\mu_{2010\ PR}, \mu_{2011\ China}, \mu_{2011\ PR})$$

An anova for all vials was done based on a weighted average demand for individual vials to calculate the WIP system value. This was done to statistically compare manufacturing system on a one to one basis and also to compare all three manufacturing systems. Tables 5.29-5.32 display the anova statistical results for WIP based on weighted demand allocations for the complete manufacturing system. The results indicate that we again reject the null hypothesis and state that the manufacturing system means are statistically different. Table 5.29 displays the anova statistical results for all three manufacturing systems. Limited 2010 Business Strategy Puerto Rico Manufacturing facility has the highest average for WIP, then Expanded 2011 Business Strategy China Manufacturing facility and then Expanded 2011 Business Strategy Puerto Rico Manufacturing facility. This concludes that the amount of inventory that is in the system will decrease with the new Expanded 2011 Business Strategy for individual manufacturing facilities. In total the Expanded 2011 system has more WIP in the manufacturing system, if both 2011 facilities are added together. We conclude that the individual Expanded 2011 Business Strategy manufacturing facility will operate more efficiently than the current Limited 2010 Business Strategy in terms of WIP.

Table 5.29 Anova Test for Manufacturing System WIP

WIP Systme Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	1083.025	108.3025	7.940217		
2011 China	10	738.2218	73.82218	3.206821		
2011 PR	10	694.9216	69.49216	5.947223		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9046.261	2	4523.13	793.798	1.03E-24	3.354131
Within Groups	153.8484	27	5.698087			
Total	9200.109	29				

Table 5.30 Anova Test for Manufacturing System WIP

WIP Systme Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	1083.025	108.3025	7.940217		
2011 China	10	738.2218	73.82218	3.206821		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5944.449	1	5944.449	1066.552	1.79E-17	4.413873
Within Groups	100.3233	18	5.573519			
Total	6044.772	19				

Table 5.31 Anova Test for Manufacturing System WIP

WIP Systme Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2011 China	10	738.2218	73.82218	3.206821		
2011 PR	10	694.9216	69.49216	5.947223		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	93.74528	1	93.74528	20.48172	0.000262	4.413873
Within Groups	82.3864	18	4.577022			
Total	176.1317	19				

Table 5.32 Anova Test for Manufacturing System WIP

WIP Systme Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	1083.025	108.3025	7.940217		
2011 PR	10	694.9216	69.49216	5.947223		
ANOVA						
ource of Variatio	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7531.197	1	7531.197	1084.605	1.54E-17	4.413873
Within Groups	124.987	18	6.94372			
Total	7656.184	19				

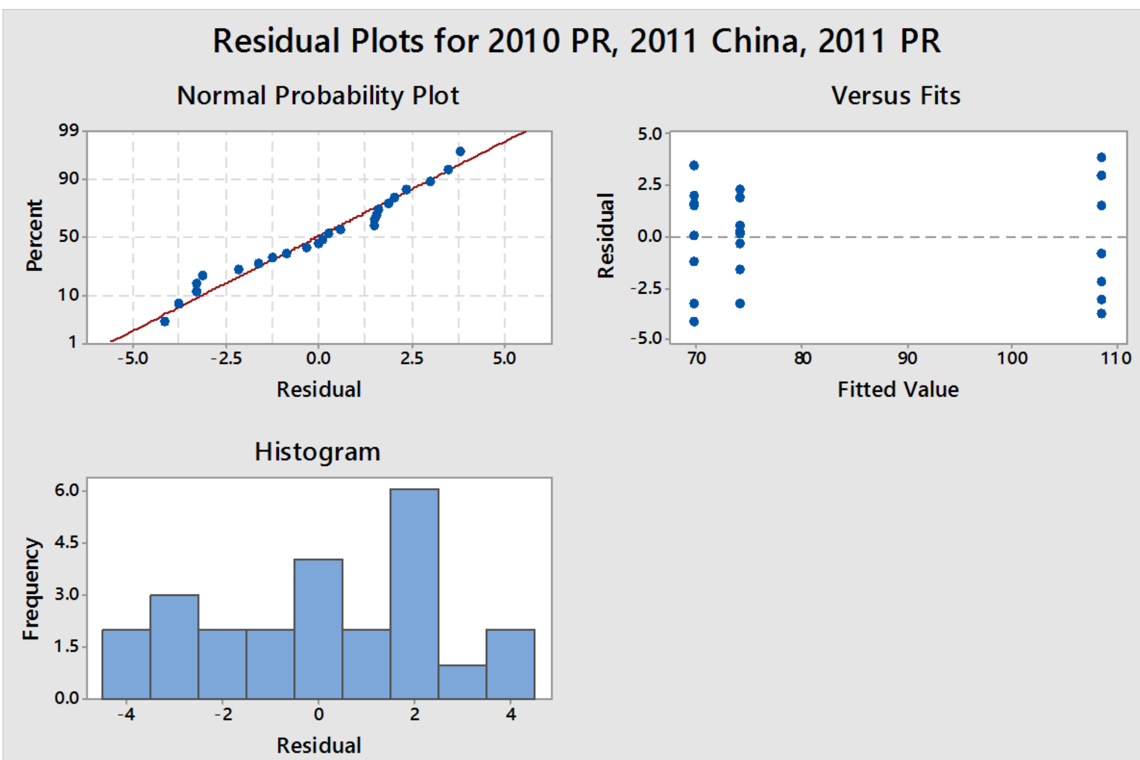

Figure 5.20 WIP Residual Plots

An Anova statistical test for all vials was done based on a weighted average demand for individual vials to calculate the flow time system value. This was done to statistically compare manufacturing system on a one to one basis and also to compare all three manufacturing systems. Tables 5.33-5.36 display the anova statistical results for WIP based on weighted demand allocations for the complete manufacturing system. The results indicate that we again reject the null hypothesis and state that the manufacturing system means are statistically different. Table 5.33 displays the anova statistical results for all three manufacturing systems. Limited 2010 Business Strategy Puerto Rico Manufacturing facility has the highest average for flow time, then Expanded 2011 Business Strategy China Manufacturing facility and then Expanded 2011 Business Strategy Puerto Rico Manufacturing facility. This concludes that the amount of flow time for vials will decrease with the new Expanded 2011 Business Strategy for individual manufacturing facilities. We conclude that the individual Expanded 2011 Business Strategy manufacturing facility will operate more efficiently than the current Limited 2010 Business Strategy in terms of flow time.

Table 5.33 Anova Test for Manufacturing System Flow Time

Flow Time System Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	4973.515	497.3515	97.60656		
2011 China	10	3283.237	328.3237	151.7898		
2011 PR	10	3478.265	347.8265	92.78163		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	171028.1	2	85514.06	749.7331	2.21E-24	3.354131
Within Groups	3079.602	27	114.0593			
Total	174107.7	29				

Table 5.34 Anova Test for Manufacturing System WIP

Flow Time System Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2011 China	10	3283.237	328.3237	151.7898		
2011 PR	10	3478.265	347.8265	92.78163		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1901.793	1	1901.793	15.55204	0.000952	4.413873
Within Groups	2201.143	18	122.2857			
Total	4102.935	19				

Table 5.35 Anova Test for Manufacturing System WIP

Flow Time System Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	4973.515	497.3515	97.60656		
2011 China	10	3283.237	328.3237	151.7898		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	142851.8	1	142851.8	1145.581	9.48E-18	4.413873
Within Groups	2244.567	18	124.6982			
Total	145096.4	19				

Table 5.36 Anova Test for Manufacturing System WIP

Flow Time System Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR	10	4973.515	497.3515	97.60656		
2011 PR	10	3478.265	347.8265	92.78163		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	111788.5	1	111788.5	1174.322	7.61E-18	4.413873
Within Groups	1713.494	18	95.1941			
Total	113502	19				

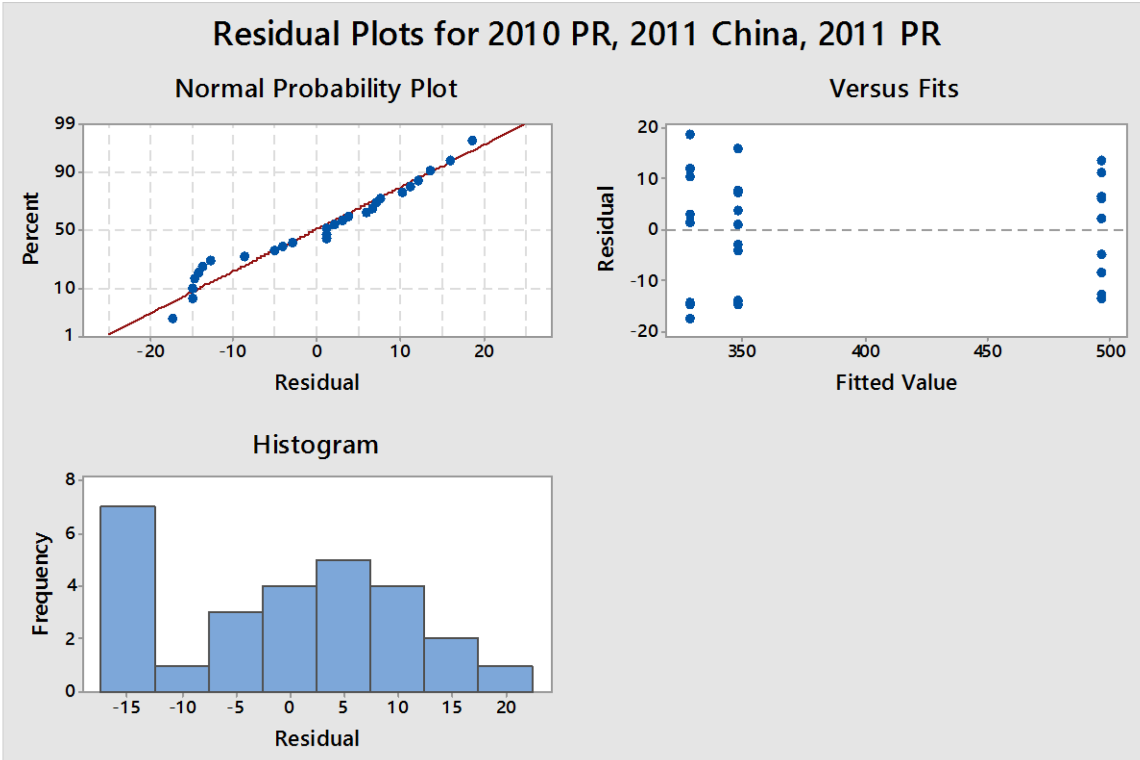

Figure 5.21 Flow Time Residual Plot

Comparing the Limited 2010 Business Strategy and the Expanded 2011 Business Strategy, Lifescan will increase yearly revenue by reducing inefficiencies in the manufacturing system in terms of WIP and flow time for vials.

6 Conclusions and Future Work

Business structures are extremely complex and difficult to understand; because of market pressure, stochastic demand and supply, government issues, prices, etc. To achieve a better understanding of modeling the business structure detailed research must conducted, as in this study. This research builds a template models to establish current demand figures along with allocating them to the manufacturing system and building models to simulate the business process. The template models are designed based on a case study from a global blood sugar monitoring industry, with four major companies; Abbott, Bayer, LifeScan, and Roche. These four companies contribute to over 90% of the industry. This study focused on the development of a business process plan for LifeScan. This study focuses the development of additional demand for developing countries, less efficient countries, or countries with less than $10,000 of GDP per capita.

6.1 Limited 2010 Business Strategy: Puerto Rico Manufacturing Facility

This study starts with a current state model, the Limited 2010 Business Strategy. This strategy has only one manufacturing facility, in Puerto Rico that supplies to all countries with GDP per capita > $10,000 and all countries that are less than this amount are referred to unsatisfied customers. This current state model was designed and implemented into Arena simulation with a total cost in table 6.1. The cost include operator and machine cost for an entire year.

Table 6.1 Limited 2010 Manufacturing System Calculations

Limited 2010 Puerto Rico Manufacturing Facility: Total Manufacturing System Cost							
16 Hours; 2 Shifts: Manufacturing Cells						8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
$ 2,071,320	$ 2,587,080	$ 2,551,320	$ 2,071,320	$ 2,551,320	$ 2,071,320	$ 1,820,660	$ 1,598,540
$ 2,587,080	$ 2,551,320		$ 2,551,320		$ 2,551,320		
$ 2,551,320					$ 3,067,080		
$ 3,582,840	$ 3,582,840	$ 2,551,320	$ 2,551,320	$ 2,551,320	$ 3,582,840	$ 1,820,660	$ 1,598,540
Total System Cost: $21,821,680							

The expected demand for the Limited 2010 business strategy is displayed in Table 6.2. The Arena simulation created 123,938 vials with the expected number of vials for demand for 2010 being 123,990. This indicates that the Limited 2010 Business Strategy Puerto Rico Manufacturing system is capable of manufacturing close to the entire amount of demand. Bottleneck resources for each manufacturing cell utilization calculations are displayed in Table 6.3.

Table 6.2 Limited 2010 Manufacturing System Demand

Limited 2010 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Expected and Simulation Demand			
Vial Type	Expected Demand	Simulation: Entities Created	Absolute % Difference
Vial 1	4,149	4,164	0.360%
Vial 2	20,707	20,764	0.275%
Vial 3	19,052	18,956	0.506%
Vial 4	70,929	70,883	0.065%
Vial 5	9,153	9,171	0.196%
Total	123,990	123,938	0.042%

Table 6.3 Limited 2010 Manufacturing System Bottleneck Resources

Limited 2010 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Bottleneck Resouce Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 6 Auto	98.60%	96.33%	2.356%
Cell 2 Machine 9	84.40%	79.25%	6.498%
Cell 3 Machine Man 6	97.10%	93.32%	4.051%
Cell 4 Machine Man 6	99.60%	87.16%	14.273%
Cell 5 Machine Man 6	99.90%	95.10%	5.047%
Cell 6 Machine Man 6	99.50%	97.40%	2.156%
Cell 7 Machine Man 6	100.00%	100.00%	0.000%
Cell 8 Machine 9	100.00%	97.49%	2.575%

6.2 Expanded 2011 Business Strategies

From a corporate perspective point of view, how would LifeScan produce blood sugar strips for 2010 unsatisfied customers and still make the required return? This question was answered in this study by cutting cost and opening up another manufacturing facility in a less wage intensive region; China. The current facility in Puerto Rico would still manufacture a percentage of the blood sugar strips. This situation is referred to the Expanded 2011 Business Strategy. This strategy operated with two different manufacturing systems, with different demands being manufactured in each facility. Demand allocation was also based on GDP per capita. Customers or individual countries where broken down into three categories; Low income customers (GDP per capita <$10,000), Floating Customers ($10,000<=GDP per capita<=$20,000), and High Income Customers (GDP per capita > $20,000). Demand distribution was allocated to different manufacturing facilities, based on GDP so Low income customers were allocated to the China manufacturing facility where High income customers were allocated to the Puerto Rico manufacturing facility. The additional demand or floating demand can be allocated based on any percentage, for this study 50% of the floating demand was allocated to the Chain manufacturing facility where the other 50% of the floating demand was allocated to the Puerto Rico manufacturing facility.

6.2.1 Expanded 2011 Business Strategy: China Manufacturing Facility

The Expanded 2011 Business manufacturing system cost calculations are displayed in Table 6.4 for the China manufacturing facility. Simulation demand and expected demand calculations are displayed in Table 6.5. Bottleneck resource utilization comparisons for expected manufacturing cell calculations and the simulation results is displayed in Table 6.6.

Table 6.4 Expanded 2011 China Manufacturing System Calculations

Expanded 2011 China Manufacturing Facility + 50% Floating: Total Manufacturing System Cost						
16 Hours; 2 Shifts: Manufacturing Cells					8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
$ 742,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 676,300.00	$ 699,700.00
$ 742,600.00	$ 1,269,400.00					
$ 789,400.00						
$ 1,222,600.00						
$ 1,339,600.00	$ 1,339,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 1,222,600.00	$ 676,300.00	$ 699,700.00
Total System Cost: $7,723,000						

Table 6.5 Expanded 2011 China Manufacturing System Demand

Expanded 2011 Business Strategy Comparison between China Manufacturing Facility: Expected			
Vial Type	Expected Demand	Simulation: Entities Created	Absolute % Difference
Vial 1	5,294	5,288	0.113%
Vial 2	26,420	26,420	0.000%
Vial 3	24,308	24,305	0.012%
Vial 4	90,494	90,710	0.238%
Vial 5	11,678	11,649	0.249%
Total	158,194	158,372	0.112%

Table 6.6 Expanded 2011 China Manufacturing System Bottleneck Resources

Expanded 2011 Business Strategy Comparison between China Manufacturing Facility: Bottleneck Resource Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 1	98.70%	99.97%	1.270%
Cell 2 Machine 1	71.40%	69.98%	2.029%
Cell 3 Machine 1	80.30%	90.27%	11.045%
Cell 4 Machine 1	98.30%	99.96%	1.661%
Cell 5 Machine 1	100.00%	100.00%	0.000%
Cell 6 Machine 1	99.50%	99.26%	0.242%
Cell 7 Machine 1	99.10%	98.34%	0.773%

6.2.2 Expanded 2011 Business Strategy: Puerto Rico Manufacturing Facility

The Expanded 2011 Business manufacturing system cost calculations are displayed in Table 6.7 for the Puerto Rico manufacturing facility. Simulation demand and expected demand calculations are displayed in Table 6.8. Bottleneck resource utilization comparisons for expected manufacturing cell calculations and the simulation results is displayed in Table 6.9.

Table 6.7 Expanded 2011 Puerto Rico Manufacturing System Calculations

Puerto Rico Manufacturing Facility + 50% Floating: Total Manufacturing System				
16 Hours; 2 Shifts: Manufacturing Cells			8 Hours; 1 Shift: Manufacturing Cells	
Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
$ 2,071,320	$ 2,071,320	$ 2,587,080	$ 1,340,660	$ 1,820,660
$ 2,551,320	$ 2,587,080	$ 2,551,320	$ 1,820,660	
	$ 2,551,320			
	$ 3,067,080			
$ 2,551,320	$ 4,062,840	$ 2,587,080	$ 1,820,660	$ 1,820,660
Total System Cost: $12,842,560				

Table 6.8 Expanded 2011 Puerto Rico Manufacturing System Demand

Expanded 2011 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Expected and Simulation Demand			
Vial Type	Expected Demand	Simulation: Entities Created	Absolute % Difference
Vial 1	3,628	3,632	0.105%
Vial 2	18,107	18,210	0.565%
Vial 3	16,659	16,691	0.191%
Vial 4	62,020	62,082	0.100%
Vial 5	8,003	8,001	0.025%
Total	108,418	108,616	0.183%

Table 6.9 Expanded 2011 Puerto Rico Manufacturing System Bottleneck Resources

Expanded 2011 Business Strategy Comparison between Puerto Rico Manufacturing Facility: Bottleneck Resource Utilization			
Bottleneck Resource	Expected Manufacturing Cell Calculations (OPL)	Simulation Bottleneck Resource	Absolute % Difference
Cell 1 Machine 1	99.70%	99.68%	0.020%
Cell 2 Machine 1	91.50%	94.98%	3.664%
Cell 3 Machine 1	85.30%	88.84%	3.985%
Cell 4 Machine 1	99.70%	99.82%	0.120%
Cell 5 Machine 1	100.00%	99.97%	0.030%

The differences between the OPL calculation and Arena Simulation model are believed to be due to queueing scheduling for the manufacturing system along with the randomness of the simulation model.

6.2.3 Combined Expanded 2011 Business Strategies

Table 6.10 displays the combined manufacturing system for Expanded 2011 Business Strategy based on operator and machine cost for both manufacturing system to give a total manufacturing system cost.

Table 6.10 Expanded 2011 Business Strategy Manufacturing Cost

Expanded 2011 China & Puerto Rico Manufacturing Facilities + 50% Floating: Total Manufacturing System Cost	
16 Hours; 2 Shifts: Manufacturing Cells	8 Hours; 1 Shift: Manufacturing Cells
All Manufacturing Cells	All Manufacturing Cells
$ 15,548,240.00	$ 5,017,320.00
Total Manufacturing System Cost: $20,565,560	

6.3 Comparisons between Limited 2010 Business Strategy and Expanded 2011 Business Strategy

Table 6.11 displays the difference between the Limited 2010 Business Strategy and the Expanded 2011 Business Strategy. Expanded 2011 Business Strategy manufacturing cells cost for manufacturing cells that operate under 2 shifts will expect to cost $346,960 less than in Limited 2010 Business Strategy because of cheaper operator cost in China. Expanded 2011 Business Strategy manufacturing cells cost for manufacturing cells that operate under 1 shift will expect to cost $1,598,120 more than in Limited 2010 Business Strategy. Totaling up both Business Strategies, Expanded 2011 Business Strategy will cost $1,251,160 more, but according to Table 6.12 the expected potential additional revenue is just under 1.5 billion dollars. This additional revenue calculation does not include the additional warehouse, distribution centers, sales representatives, etc. that are needed to achieve these additional revenues.

Table 6.11 Comparison between 2010 and 2011 Business Strategy

Cost Comparison Between Limited 2010 Business Strategy and Expanded 2011 Business Strategy: Total Manufacturing System Cost	
16 Hours; 2 Shifts: Manufacturing Cells	8 Hours; 1 Shift: Manufacturing Cells
All Cells	All Cells
$ (2,854,240.00)	$ 1,598,120.00
2011 Total Manufacturing System Cost Difference: ($1,256,120)	

Table 6.12 Comparison between 2010 and 2011 Business Strategies

Region	2010 Global Market Revenue	2011 Potential Global Market Revenue	Global Revenue increase % from 2010 to 2011	2010 Lifescan Revenue of World Market	2011 Lifescan Revenue of World Market	Lifescan Revenue increase % from 2010 to	2010 Lifescan Market Share based on	2011 Lifescan Market Share based on	Lifescan Market Share % from 2010 to
Africa & Middle East	$ 420,260,000	$ 1,192,210,000	183.68%	$ 107,418,456	$ 377,600,956	251.52%	1.21%	2.92%	141.32%
Asia	$ 1,436,050,000	$ 4,058,150,000	182.59%	$ 364,900,305	$ 1,282,635,305	251.50%	4.11%	9.91%	141.12%
Europe	$ 3,237,860,000	$ 3,410,220,000	5.32%	$ 773,524,754	$ 833,850,754	7.80%	8.71%	6.44%	-26.06%
Latin America	$ 605,250,000	$ 1,066,760,000	76.25%	$ 154,701,900	$ 316,230,400	104.41%	1.74%	2.44%	40.23%
North America & The Caribb	$ 3,008,190,000	$ 3,042,910,000	1.15%	$ 933,742,176	$ 945,894,176	1.30%	10.51%	7.31%	-30.45%
Oceana	$ 176,400,000	$ 177,850,000	0.82%	$ 45,087,840	$ 45,595,340	1.13%	0.51%	0.35%	-31.37%
Total	$ 8,884,010,000	$ 12,948,100,000	45.75%	$ 2,379,375,431	$ 3,801,806,931	59.78%	26.79%	29.37%	9.63%

Based on the study, LifeScan should look into an additional manufacturing facility in China to produce additional revenues for the company. The Expanded 2011 Business Strategy will account for LifeScan taking on debt but will produce high return for the company. According to this study, now is the time for the Pharmaceutical industry to become a true global market. New facility cost in China could be considered. Puerto Rico manufacturing facility may need to labor readjustments within the facility.

6.4 Future Work

This thesis manufacturing system and simulation can be extended by considering more constraints for the mathematical model to include machine and worker costs, expanding upon the connected manufacturing system to split it up, shared and remainder manufacturing cells may need changeover time to be added to the mathematical model, apply queueing theory or reconstruct the queuing scheduling to limit when manufacturing cells can receive products, and look into code to further expand upon how products are called into the queue.

This thesis supply chain and demand forecast can be extended by building a supply chain network for the current information, build econometric statistical models to better forecast future demand, build distribution networks for the new facility, and figure out where and how we will sell additional products to low income countries.

This thesis additional areas can be extended by worker allocation needs to be re calculated and to figure out where Puerto Rico workers will go, reallocating demand forecast for floating demand, and apply strategies to additional businesses.

Reasons to keep Puerto Rico manufacturing facility:

- Government gives tax benefits for domestic produce.
- Highly skilled workers liver in Puerto Rico so the deployment of new products and for future research of blood sugar products.
- Reliability of workers, government, insurance companies, etc. in the US

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Appendix A Matlab Code for Manufacturing Cells

Matlab code

```
clear;
clc;

[ndata, headertext] = xlsread('D:\Thesis\ExpUtilizationFAST_ASIA.xlsx');
for i = 1:40
   Mu(i) = ndata(i);
end
for i = 41:80
   Std(i-40) = ndata(i);
end
for i = 81:120
   A(i-80) = ndata(i);
end

for i = 121:160
   range(i-120)= ndata(i);
end



   for i = 1:40

      f = @(x) x.*exp((-(x-Mu(i)).^2)./(2*(Std(i).^2)))./(2000*sqrt(2*pi).*Std(i).*A(i));
      integrationValues(i)=quad((f),range(i),range(i)+2000)-range(i)/2000;
   end

integrationValues'
[status,msg]=xlswrite('D:\Thesis\ExpUtilizationFAST_ASIA.xlsx',integrationValues','H2:H41')
```

Appendix B Shift Allocations that is used for the OPL Mathematical Model

Limited 2010 Shift Allocation

2010 Standard Puerto Rico Manufacturing Facility: Shift Allocation														
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8	CS 9	CS 10	CS 11	CS 12	CS 13
Family 1	1	Shift 1												
	2	Shift 2												
Family 2	1	Shift 1	Shift 1	Shift 1	Shift 1									
	2	Shift 1	Shift 1	Shift 1	Shift 2									
	3	Shift 1	Shift 1	Shift 2										
	4	Shift 1	Shift 2	Shift 1										
	5	Shift 1	Shift 2	Shift 2										
	6	Shift 2	Shift 1	Shift 1										
	7	Shift 2	Shift 1	Shift 2										
	8	Shift 2	Shift 2											
Family 3	1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1								
	2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2								
	3	Shift 1	Shift 1	Shift 1	Shift 2									
	4	Shift 1	Shift 1	Shift 2	Shift 1									
	5	Shift 1	Shift 1	Shift 2	Shift 2									
	6	Shift 1	Shift 2	Shift 1	Shift 1									
	7	Shift 1	Shift 2	Shift 1	Shift 2									
	8	Shift 1	Shift 2	Shift 2										
	9	Shift 2	Shift 1	Shift 1	Shift 1									
	10	Shift 2	Shift 1	Shift 1	Shift 2									
	11	Shift 2	Shift 1	Shift 2										
	12	Shift 2	Shift 2	Shift 1										
	13	Shift 2	Shift 2	Shift 2										
Family 4	1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1
	2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2
	3	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	
	4	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2		
	5	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1		
	6	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2		
	7	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2			
	8	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1			
	9	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2			
	10	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2				
	11	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 1				
	12	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2					
	13	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2					
	14	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2						
	15	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2						
	16	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2	Shift 2							
Family 5	1	Shift 1	Shift 1											
	2	Shift 1	Shift 2											
	3	Shift 2												

Limited 2010 Demand Coverage

2010 Standard Puerto Rico Manufacturing Facility: Demand Coverage														
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8	CS 9	CS 10	CS 11	CS 12	CS 13
Family 1	1	1												
	2	1												
Family 2	1	0.01595	0.36950	0.55555	0.05868									
	2	0.01595	0.36950	0.55555	0.05868									
	3	0.015953	0.369502	0.61423										
	4	0.015953	0.925047	0.058684										
	5	0.015953	0.925047	0.058684										
	6	0.385455	0.555545	0.058684										
	7	0.385455	0.555545	0.058684										
	8	0.385455	0.61423											
Family 3	1	0.003418	0.140769	0.575317	0.267437	0.013005								
	2	0.003418	0.140769	0.575317	0.267437	0.013005								
	3	0.003418	0.140769	0.575317	0.280442									
	4	0.003418	0.140769	0.842754	0.013005									
	5	0.003418	0.140769	0.842754	0.013005									
	6	0.003418	0.716085	0.267437	0.013005									
	7	0.003418	0.716085	0.267437	0.013005									
	8	0.003418	0.716085	0.280442										
	9	0.144186	0.575317	0.267437	0.013005									
	10	0.144186	0.575317	0.267437	0.013005									
	11	0.144186	0.575317	0.280442										
	12	0.144186	0.842754	0.013005										
	13	0.144186	0.842754	0.013005										
Family 4	1	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.109304	0.045386	0.013455	
	2	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.109304	0.045386	0.013455	
	3	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.109304	0.045386	0.013458	
	4	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.109304	0.058841		
	5	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.154690	0.013455		
	6	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.187989	0.154690	0.013455		
	7	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.230936	0.297293	0.058841			
	8	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.418925	0.154690	0.013455			
	9	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.202649	0.418925	0.154690	0.013455			
	10	0.000085	0.000675	0.004146	0.018173	0.056859	0.127019	0.433584	0.297293	0.058841				
	11	0.000085	0.000675	0.004146	0.018173	0.056859	0.329667	0.418925	0.154690	0.013455				
	12	0.000085	0.000675	0.004146	0.018173	0.183878	0.433584	0.297293	0.058841					
	13	0.000085	0.000675	0.004146	0.075032	0.329667	0.418925	0.154690	0.016301					
	14	0.000085	0.000675	0.022318	0.183878	0.433584	0.297293	0.058841						
	15	0.000085	0.004820	0.075032	0.329667	0.418925	0.154690	0.016301						
	16	0.007599	0.022318	0.183878	0.433584	0.297293	0.058841							
Family 5	1	0.59198	0.40802											
	2	0.59198	0.40802											
	3	1												

Limited 2010 Utilization

2010 Standard Puerto Rico Manufacturing Facility: Utilization Totals														
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8	CS 9	CS 10	CS 11	CS 12	CS 13
Family 1	1	0.432												
	2	0.216												
Family 2	1	0.996923	0.8565725	0.287609	0.012859916									
	2	0.996923	0.8565725	0.287609	0.006429958									
	3	0.996923	0.8565725	0.151587										
	4	0.996923	0.57311075	0.012861										
	5	0.996923	0.57311075	0.006431										
	6	0.92755	0.28762673	0.012861										
	7	0.92755	0.28762673	0.006431										
	8	0.92755	0.15158731											
Family 3	1	0.999751	0.95525034	0.586477	0.104108454	0.002679434								
	2	0.999751	0.95525034	0.586477	0.104108454	0.001339717								
	3	0.999751	0.95525034	0.586477	0.053397743									
	4	0.999751	0.95525034	0.343815	0.002679434									
	5	0.999751	0.95525034	0.343815	0.001339717									
	6	0.999751	0.77076656	0.104108	0.002679434									
	7	0.999751	0.77076656	0.104108	0.001339717									
	8	0.999751	0.77076656	0.053398										
	9	0.977663	0.58647731	0.104108	0.002679434									
	10	0.977663	0.58647731	0.104108	0.001339717									
	11	0.977663	0.58647731	0.053398										
	12	0.977663	0.34381498	0.002679										
	13	0.977663	0.34381498	0.00134										
Family 4	1	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.110414594	0.035671113	0.008616816	0.001541471
	2	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.110414594	0.035671113	0.008616816	0.000770736
	3	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.110414594	0.035671113	0.005077355	
	4	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.110414594	0.03820979		
	5	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.073040933	0.008616816		
	6	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.259488493	0.073040933	0.004308408		
	7	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.47403711	0.184952958	0.022146126			
	8	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.366758742	0.073040933	0.008616816			
	9	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.696721335	0.366758742	0.073040933	0.004308408			
	10	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.863314355	0.585373477	0.184952958	0.022146126				
	11	0.999966	0.99968149	0.997724	0.987980282	0.95312009	0.780022881	0.366758742	0.073040933	0.008616816				
	12	0.999966	0.99968149	0.997724	0.987980282	0.908217422	0.585373477	0.184952958	0.022146126					
	13	0.999966	0.99968149	0.997724	0.970549045	0.780022881	0.366758742	0.073040933	0.005077355					
	14	0.999966	0.99968149	0.992854	0.908217422	0.585373477	0.184952958	0.022146126						
	15	0.999966	0.99870042	0.970549	0.780022881	0.366758742	0.073040933	0.005077355						
	16	0.999826	0.9928541	0.908217	0.585373477	0.184952958	0.022146126							
Family 5	1	0.89476	0.05873985											
	2	0.89476	0.02936993											
	3	0.47675												

Expanded 2011 Shift Allocation

2011 Expanded Puerto Rico Manufacturing Facility + 50% Floating: Shift Allocation									
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8
Family 1	1	Shift 1							
	2	Shift 2							
Family 2	1	Shift 1	Shift 1	Shift 1					
	2	Shift 1	Shift 2						
	3	Shift 2	Shift 1						
	4	Shift 2	Shift 2						
Family 3	1	Shift 1	Shift 1	Shift 1					
	2	Shift 1	Shift 2						
	3	Shift 2	Shift 1						
	4	Shift 2	Shift 2						
Family 4	1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1
	2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	
	3	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 1	
	4	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	
	5	Shift 1	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2		
	6	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 1		
	7	Shift 1	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2		
	8	Shift 1	Shift 1	Shift 2	Shift 2	Shift 2			
	9	Shift 1	Shift 2	Shift 2	Shift 2	Shift 1			
	10	Shift 1	Shift 2	Shift 2	Shift 2	Shift 2			
	11	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	Shift 1	
	12	Shift 2	Shift 2	Shift 1	Shift 1	Shift 1	Shift 1		
	13	Shift 2	Shift 2	Shift 2	Shift 1	Shift 1			
	14	Shift 2	Shift 2	Shift 2	Shift 2				
Family 5	1	Shift 1							
	2	Shift 2							

Expanded 2011 Demand Coverage

2011 Expanded Puerto Rico Manufacturing Facility + 50% Floating: Demand Coverage									
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8
Family 1	1	1							
	2	1							
Family 2	1	0.2064	0.7845	0.0091					
	2	0.2064	0.7936						
	3	0.9909	0.0091						
	4	0.9909	0.0091						
Family 3	1	0.2777	0.7215	0.0008					
	2	0.2777	0.7223						
	3	0.9992	0.0008						
	4	0.9992	0.0008						
Family 4	1	0.000421	0.009512	0.083591	0.284806	0.379587	0.198367	0.040437	0.003181
	2	0.000421	0.009512	0.083591	0.284806	0.379587	0.198367	0.043619	
	3	0.000421	0.009512	0.083591	0.284806	0.379587	0.238804	0.003181	
	4	0.000421	0.009512	0.083591	0.284806	0.379587	0.238804	0.003181	
	5	0.000421	0.009512	0.083591	0.284806	0.577954	0.043619		
	6	0.000421	0.009512	0.083591	0.664393	0.238804	0.003181		
	7	0.000421	0.009512	0.083591	0.664393	0.238804	0.003181		
	8	0.000421	0.009512	0.368397	0.577954	0.043619			
	9	0.000421	0.093103	0.664393	0.238804	0.003181			
	10	0.000421	0.093103	0.664393	0.238804	0.003181			
	11	0.009934	0.083591	0.284806	0.379587	0.198367	0.040437	0.003181	
	12	0.009934	0.368397	0.379587	0.198367	0.040437	0.003181		
	13	0.009934	0.368397	0.577954	0.040437	0.003181			
	14	0.009934	0.368397	0.577954	0.043619				
Family 5	1	1							
	2	1							

Expanded 2011 Utilization

2011 Expanded Puerto Rico Manufacturing Facility + 50% Floating: Utilization Totals									
	Option	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	CS 7	CS 8
Family 1	1	0.252							
	2	0.126							
Family 2	1	0.9635	0.293	0.001					
	2	0.9635	0.2748						
	3	0.6282	0.0005						
	4	0.6282	0.00025						
Family 3	1	0.9542	0.2028	0.00004					
	2	0.9542	0.1014						
	3	0.5785	0.00004						
	4	0.5785	0.00002						
Family 4	1	0.9999	0.9968	0.96	0.7827	0.426	0.1239	0.0167	0.001
	2	0.9999	0.9968	0.96	0.7827	0.426	0.1239	0.00885	
	3	0.9999	0.9968	0.96	0.7827	0.426	0.0703	0.001	
	4	0.9999	0.9968	0.96	0.7827	0.426	0.0703	0.0005	
	5	0.9999	0.9968	0.96	0.7827	0.275	0.0088		
	6	0.9999	0.9968	0.9600	0.6044	0.0703	0.0010		
	7	0.9999	0.9968	0.9600	0.6044	0.0703	0.000476		
	8	0.999892	0.996768	0.871375	0.274983	0.008813			
	9	0.999892	0.978385	0.604384	0.070299	0.000953			
	10	0.999892	0.978385	0.604384	0.070299	0.000476			
	11	0.998329	0.960004	0.782748	0.42603	0.123934	0.016672	0.000953	
	12	0.998329	0.871375	0.42603	0.123934	0.016672	0.000953		
	13	0.998329	0.871375	0.274983	0.016672	0.000953			
	14	0.998329	0.871375	0.274983	0.008813				
Family 5	1	0.55596							
	2	0.27798							

Appendix C Queueing Theory Scheduling That is Used for the Simulation Model to Dynamically Select the Queue

Limited 2010 Queuing Theory

2010 Business Strategy: Puerto Rico Manufacturing Facility							
Family 1	21.6%						
Start time(hr)	12.544						
Start time (min)	752.64						
Total Production	3.46						
Family 2	92.8%	15.2%					
Start time(hr)	0.576	13.568					
Start time (min)	34.56	814.08					
Total Production	15.42	2.43					
Family 3	100.0%	77.100%	5.300%				
Start time(hr)	0	3.664	15.152				
Start time (min)	0	219.84	909.12				
Total Production	8.00	12.34	0.85				
					352.32		
Family 4	100.0%	99.9%	97.1%	78.0%	36.7%	7.3%	0.5%
Start time(hr)	0	0.016	0.464	3.52	10.128	14.832	15.92
Start time (min)	0	0.96	27.84	211.2	607.68	889.92	955.2
Total Production	8.00	15.98	15.54	12.48	5.87	1.17	0.08
Family 5	47.7%						
Start time(hr)	8.368						
Start time (min)	502.08						
Total Production	7.63						

Expanded 2011 Queueing Theory

2011 Expanded Business Strategy: Puerto Rico + 50% Floating						
Family 1	12.6%					
Start time(hr)	13.984					
Start time (min)	839.04					
Total Production	2.02					
Family 2	99.1%	0.9%				
Start time(hr)	0.0728	15.8544				
Start time (min)	4.368	951.264				
Total Production	15.93	0.15				
Family 3	57.9%	0.002%				
Start time(hr)	3.372	15.99968				
Start time (min)	202.32	959.9808				
Total Production	12.63	0.00				
Family 4	100.0%	99.7%	87.1%	27.5%	0.9%	
Start time(hr)	0	0.0512	2.058	11.60027	15.85899	
Start time (min)	0	3.072	123.48	696.0163	951.5395	
Total Production	8.00	7.95	13.94	4.40	0.14	
Family 5	27.8%					
Start time(hr)	11.55232					
Start time (min)	693.1392					
Total Production	4.45					

Appendix D The Work In Process (WIP) for the Anova Tables

WIP Vial 2

WIP Vial 2 Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 2	10	233.7279	23.37279	2.140599		
2011 China: Vial 2	10	499.6846	49.96846	14.64955		
2011 PR: Vial 2	10	156.4118	15.64118	0.405838		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6484.899	2	3242.449	565.6754	9.15E-23	3.354131
Within Groups	154.7639	27	5.731996			
Total	6639.663	29				

WIP Vial 3

WIP Vial 3 Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 3	10	392.8965	39.28965	1.249014		
2011 China: Vial 3	10	506.2855	50.62855	11.18651		
2011 PR: Vial 3	10	186.2375	18.62375	0.243715		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5266.524	2	2633.262	623.049	2.56E-23	3.354131
Within Groups	114.1131	27	4.226413			
Total	5380.637	29				

WIP Vial 4

WIP Vial 4 Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 4	10	1691.16	169.116	22.75843		
2011 China: Vial 4	10	990.441	99.0441	3.199495		
2011 PR: Vial 4	10	1106.71	110.671	17.08277		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28203.58	2	14101.79	982.9158	6.03E-26	3.354131
Within Groups	387.3662	27	14.3469			
Total	28590.95	29				

WIP Vial 5

WIP Vial 5 Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 5	10	200.2999	20.02999	0.32092		
2011 China: Vial 5	10	103.7656	10.37656	0.017799		
2011 PR: Vial 5	10	82.7774	8.27774	0.134775		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	785.6971	2	392.8486	2489.045	2.41E-31	3.354131
Within Groups	4.261439	27	0.157831			
Total	789.9586	29				

WIP Anova

Vial 5 Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 5	10	5244.21	524.421	190.8439		
2011 China: Vial 5	10	2141.085	214.1085	3.896518		
2011 PR: Vial 5	10	2482.426	248.2426	58.79535		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	579111.7149	2	289555.9	3426.213	3.28E-33	3.354131
Within Groups	2281.82193	27	84.51192			
Total	581393.5369	29				

WIP

WIP Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	51.7732	5.17732	0.045508		
2011 China: Vial 1	10	67.1431	6.71431	0.242713		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.81169	1	11.81169	81.9626	4.03E-08	4.413873
Within Groups	2.593993	18	0.144111			
Total	14.40568	19				

WIP Vial 1 PR vs PR

WIP Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	51.7732	5.17732	0.045508		
2011 PR: Vial 1	10	42.3408	4.23408	0.026395		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.448508	1	4.448508	123.736	1.69E-09	4.413873
Within Groups	0.647129	18	0.035952			
Total	5.095637	19				

WIP China vs PR

WIP Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2011 China: Vial 1	10	67.1431	6.71431	0.242713		
2011 PR: Vial 1	10	42.3408	4.23408	0.026395		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.7577	1	30.7577	228.5902	1.13E-11	4.413873
Within Groups	2.42197	18	0.134554			
Total	33.17967	19				

Appendix E The Flow Time for the Anova Tables

Flow Time Vial 2

Vial 2 Flow Time Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2010 PR: Vial 2	10	2702.9	270.29	219.85
2011 China: Vial 2	10	4542.56	454.256	1068.984
2011 PR: Vial 2	10	2060.1	206.01	60.07029

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	332004.9677	2	166002.5	369.1941	2.46E-20	3.354131
Within Groups	12140.13609	27	449.6347			
Total	344145.1038	29				

Flow Time Vial 3

Vial 3 Flow Time Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2010 PR: Vial 3	10	4965.56	496.556	143.724
2011 China: Vial 3	10	4994.89	499.489	1070.24
2011 PR: Vial 3	10	2679.274	267.9274	38.55592

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	353001.3487	2	176500.7	422.7494	4.2E-21	3.354131
Within Groups	11272.67801	27	417.5066			
Total	364274.0267	29				

Flow Time Vial 4

Vial 4 Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 4	10	5722.58	572.258	215.9636		
2011 China: Vial 4	10	2618.69	261.869	15.67121		
2011 PR: Vial 4	10	4277.14	427.714	205.0137		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	482462.8776	2	241231.4	1657.384	5.62E-29	3.354131
Within Groups	3929.83649	27	145.5495			
Total	486392.7141	29				

Flow Time Vial 5

WIP Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	51.7732	5.17732	0.045508		
2011 China: Vial 1	10	67.1431	6.71431	0.242713		
2011 PR: Vial 1	10	42.3408	4.23408	0.026395		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	31.34527	2	15.67263	149.4452	2.49E-15	3.354131
Within Groups	2.831546	27	0.104872			
Total	34.17682	29				

Flow Time Vial 1

Vial 1 Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	2984.87	298.487	80.56258		
2011 China: Vial 1	10	3039.86	303.986	439.2656		
2011 PR: Vial 1	10	2798.95	279.895	105.3886		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3187.592	2	1593.796	7.647569	0.002336	3.354131
Within Groups	5626.951	27	208.4056			
Total	8814.544	29				

Flow Time Vial 1 China vs PR

Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2011 China: Vial 1	10	3039.86	303.986	439.2656		
2011 PR: Vial 1	10	2798.95	279.895	105.3886		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2901.881	1	2901.881	10.65587	0.004307	4.413873
Within Groups	4901.888	18	272.3271			
Total	7803.769	19				

Flow Time PR vs China

Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	2984.87	298.487	80.56258		
2011 China: Vial 1	10	3039.86	303.986	439.2656		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	151.195	1	151.195	0.581711	0.455522	4.413873
Within Groups	4678.454	18	259.9141			
Total	4829.649	19				

Flow Time Vial 1 PR vs PR

Flow Time Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2010 PR: Vial 1	10	2984.87	298.487	80.56258		
2011 PR: Vial 1	10	2798.95	279.895	105.3886		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1728.312	1	1728.312	18.58888	0.00042	4.413873
Within Groups	1673.561	18	92.9756			
Total	3401.873	19				

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